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McClellan Air Force Base

Davis Global Communications Site

Remedial Investigation/ Feasibility Study Report

Volume II of III

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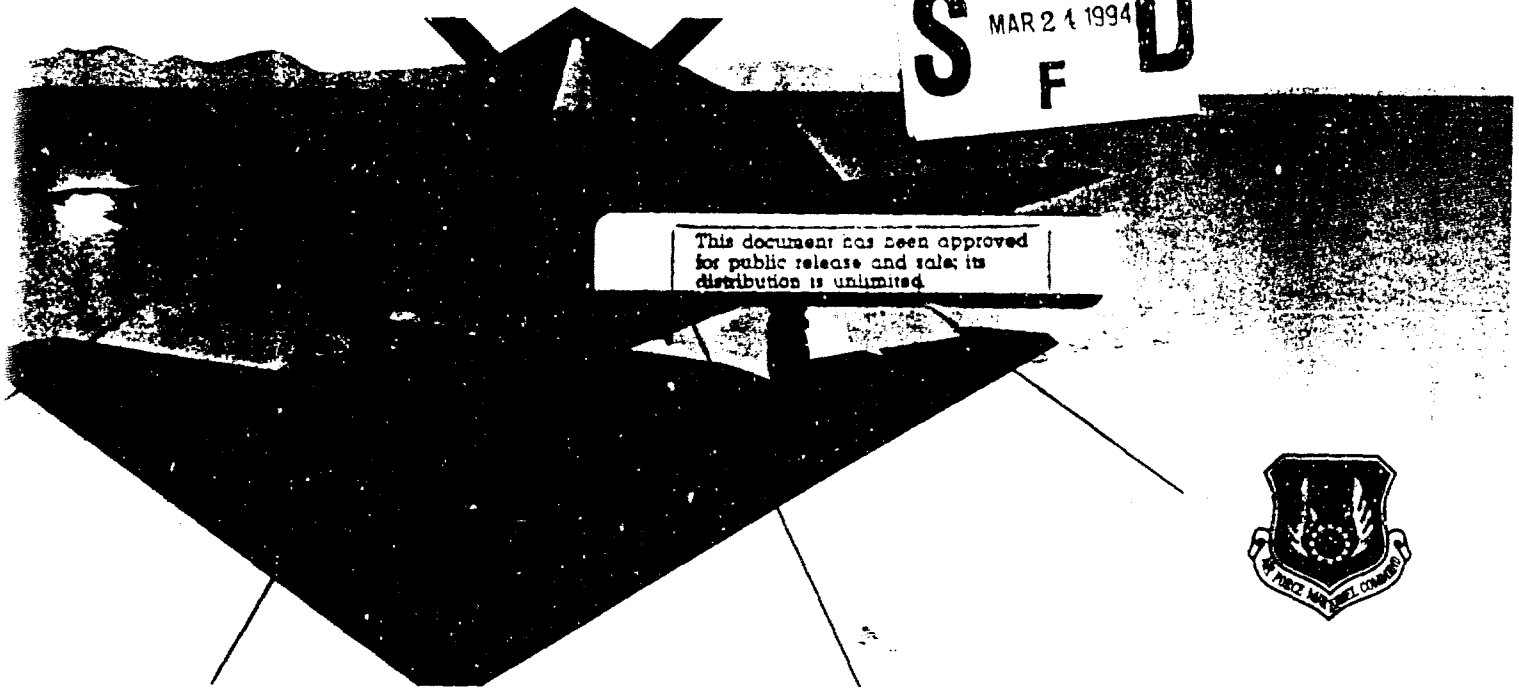

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The above mentioned document is attached for your review and records. This document is identified as a primary document according to the guidelines promulgated in our Federal Facilities Site Remediation Agreement (FFSRA).

We have endeavored to include all comments and concerns in this revision of the document. If you have any further questions, please call me at (916) 643-0830, ext 381.

J. STEVEN HODGE
Remedial Project Manager, Davis Site
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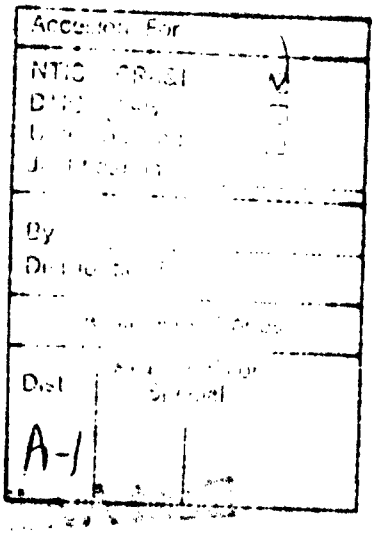

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Davis Site
Remedial Investigation/Feasibility Study Report

Volume II of III

Prepared for

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Prepared by

CH2MHILL
2485 Natomas Park Drive, Suite 600
Sacramento, California 95833

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This report has been prepared for the Air Force by CH2M HILL for the purpose of aiding in the implementation of a final remedial action plan under the Air Force Installation Restoration Program (IRP). Because the report relates to actual or possible releases of potentially hazardous substances, its release prior to an Air Force final decision on remedial action may be in the public's interest. The limited objectives of this report and the ongoing nature of the IRP, along with the evolving knowledge of site conditions and chemical effects on the environment and health, must be considered when evaluating this report, since subsequent facts may become known that may make this report premature or inaccurate. Acceptance of this report in performance of the contract under which it is prepared does not mean that the Air Force adopts the conclusions, recommendations, or other views expressed herein, which are those of the contractor only and do not necessarily reflect the official position of the Air Force.

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Risk Assessment ..... **Bound Separately**

Response to Comments

The Response to Comments is divided into two sections: the Draft Final Response to Comments and the Draft Response to Comments.

The Draft Final Response to Comments (pages RC-1 through RC-3) includes responses to comments generated by the Draft report that were not complete or that were still undecided at the time the Draft Final report was prepared.

The Draft Response to Comments (pages RC-5 through RC-39) includes responses to comments that were complete and included in the Draft Final report.

Attachments RC-1, RC-2, and RC-3 follow the Draft Final Response to Comments. Attachment RC-1 includes the Time versus Concentration plots. Attachment RC-2 includes the vertical gradients, and Attachment RC-3 includes letters stating the comments have been adequately addressed.

SUBJECT: Draft Final Remedial Investigation/
Feasibility Study
Davis Global Communications Site
McClellan Air Force Base

PROJECT: SWE28722.55.19

DATE: February 23, 1994

Mark Malinowski
Department of Substances Control

Volume I of III

General Comments

1. **The report is well written and organized. The groundwater mass and volumes should be updated to include the most recent groundwater sampling data.**

Response:

The April and July 1993 groundwater sampling data have been included in Appendix U as Tables U-4 and U-5, respectively.

4. **The monitor well Concentration versus Time plots should use a log scale along the concentration axis. The log scale provides better resolution at low concentrations.**

Response:

The monitoring well Concentration versus Time plots provided in Volume I of the RI/FS report were not changed; however, log plots of Concentration versus Time for all wells are included in Attachment RC-1 to this Response to Comments.

Volume II of III

Specific Comments

6. **Page E-1. Provide concentration plots for all wells. Use the same scale (log) for all the wells. Provide tables, like J-1, for all the sampling episodes. Include groundwater elevations and detection limits.**

Response:

Concentration versus Time plots using a log scale for concentration are provided in Attachment RC-1 to this Response to Comments. A table was not created for each sampling episode; however, this information is available in Appendix U.

Mark D. Vest, R.G.
Associate Engineering Geologist
Base Closure Branch
Department of Toxic Substances Control

General Comments

3. Tabular summaries of analytical data should be provided to support the illustrated distribution of contamination.

Response:

Concentration versus Time plots using a log scale for concentration are provided in Attachment RC-1 to this Response to Comments. A table was not created for each sampling episode; however, this information is available in Appendix U.

Chapter 2, Field Investigation Activities

13. Page 2-8, Table 2-2, Well Construction Data.

Recommendations:

a. An amended version of the table should be provided as part of Appendix S, Well Construction Data. In addition to the information provided on Table 2-2, the amended table should include well location, borehole diameter, total depth, drilling method, filter pack size gradation and interval, and surface completion type.

b. MWD-2 should be listed with the C Aquifer wells. A foot note should be provided to explain the MWD label. Alternatively, MWD-2 could be renamed MWC-2 with a foot note reminding readers of the former label.

Response:

a. The amended table is included as an addendum to Appendix S in the Draft Final report and will be included at the beginning of Appendix S in the Final report.

b. MWD-2 is included in the list of C Aquifer wells in Table 2-2 and S-1 with the following note:

> MWD-2 is screened within the C Aquifer. In future CH2M HILL documents, this well will be referred to as MWC-2.

18. **Pages 3-10 to 3-15 provide an effective discussion and presentation of ground water elevations, gradients and fluctuations that occurred between July 1992 and July 1993.**

Recommendations:

a. The discussion and graphics should be amended to evaluate available historic elevation and gradient data for consistency with the trends clearly identified in the Report.

b. In addition to the MW3 well cluster, vertical gradients should be calculated for well clusters across the site.

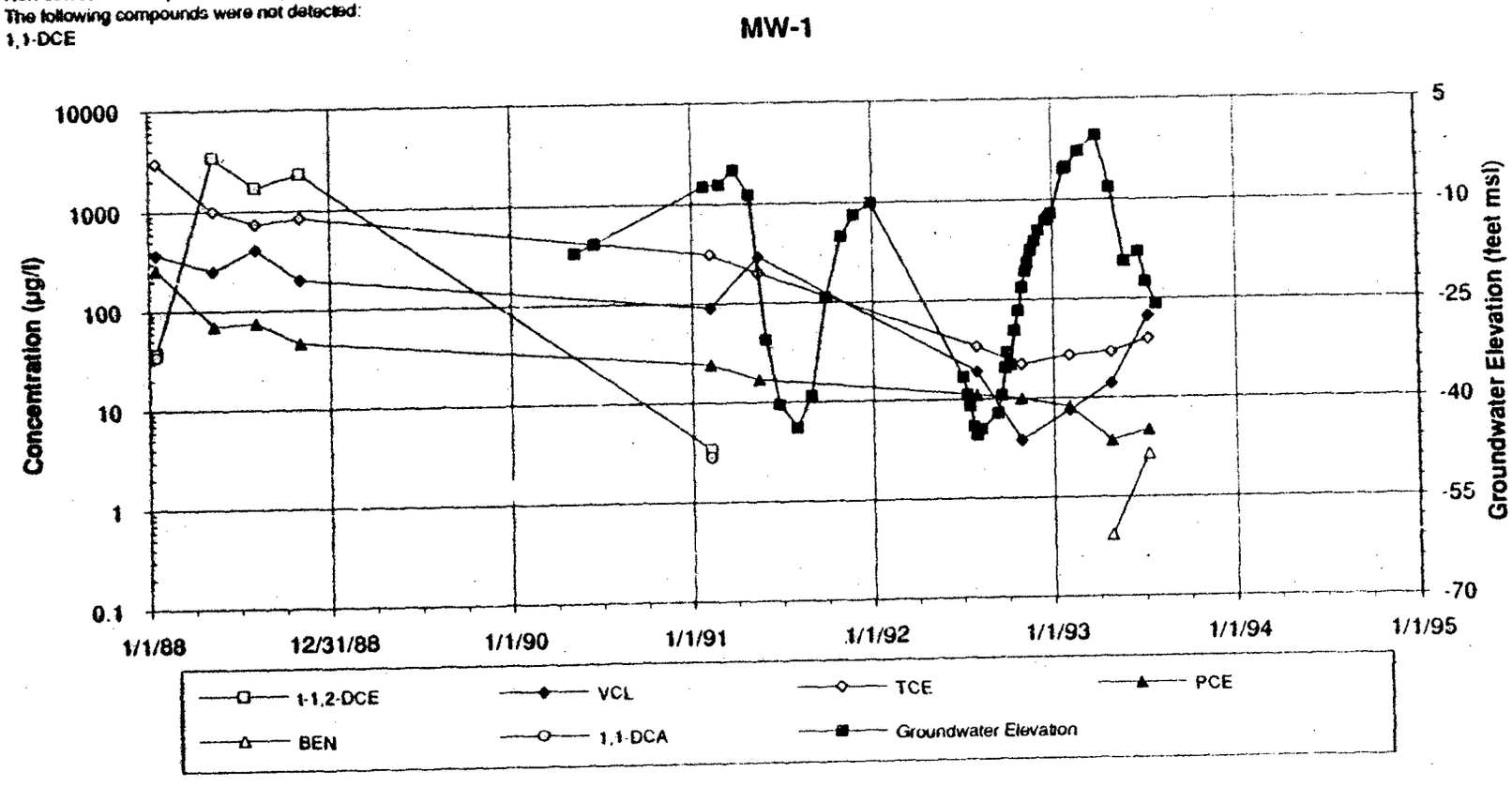
Response:

Vertical gradients for well clusters are included in Attachment 2 to this Response to Comments. The following text was added to Chapter 3 to address horizontal gradients:

> "The horizontal gradients measured in the B, C, and D aquifers between July 1992 and July 1993 are generally consistent with those measured during 1990 and 1991. Groundwater flow directions within each aquifer varied according to the season. During 1991, groundwater levels within the B and C aquifers were nearly the same. Groundwater flowed to the west-southwest during the winter and to the south during the spring and summer. D aquifer groundwater flowed to the west during the winter and to the east-southeast during the summer."

Attachment RC-1

Note:
Non detects for compounds will appear as a break in the data series.
The following compounds were not detected:
1,1-DCE



G:\users\da\emr\davislog\MW-1LOG.XLC

Note:
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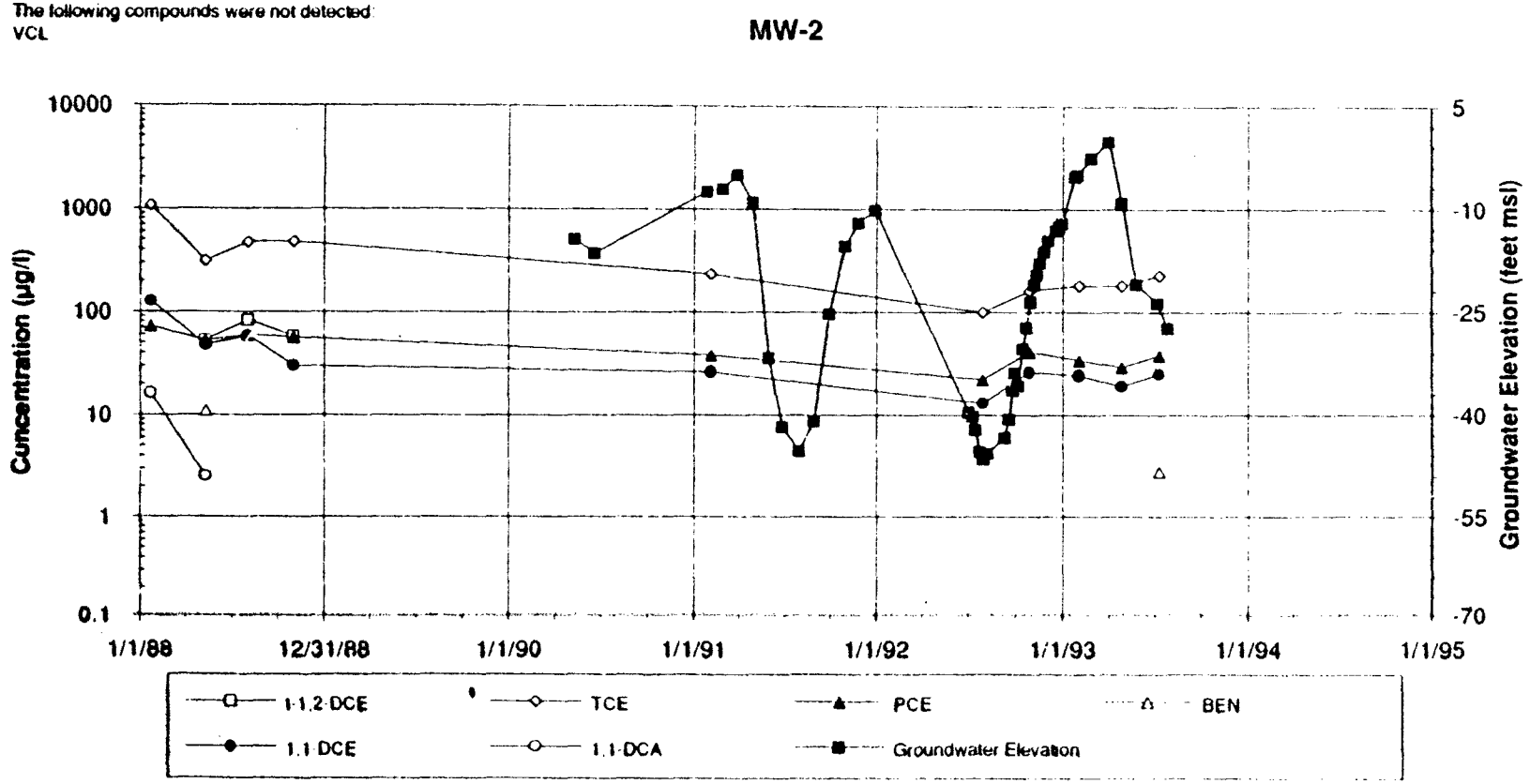
The following compounds were not detected:
VCL



G:\users\davem\data\slog\MW-2LOG.XLC

Note:
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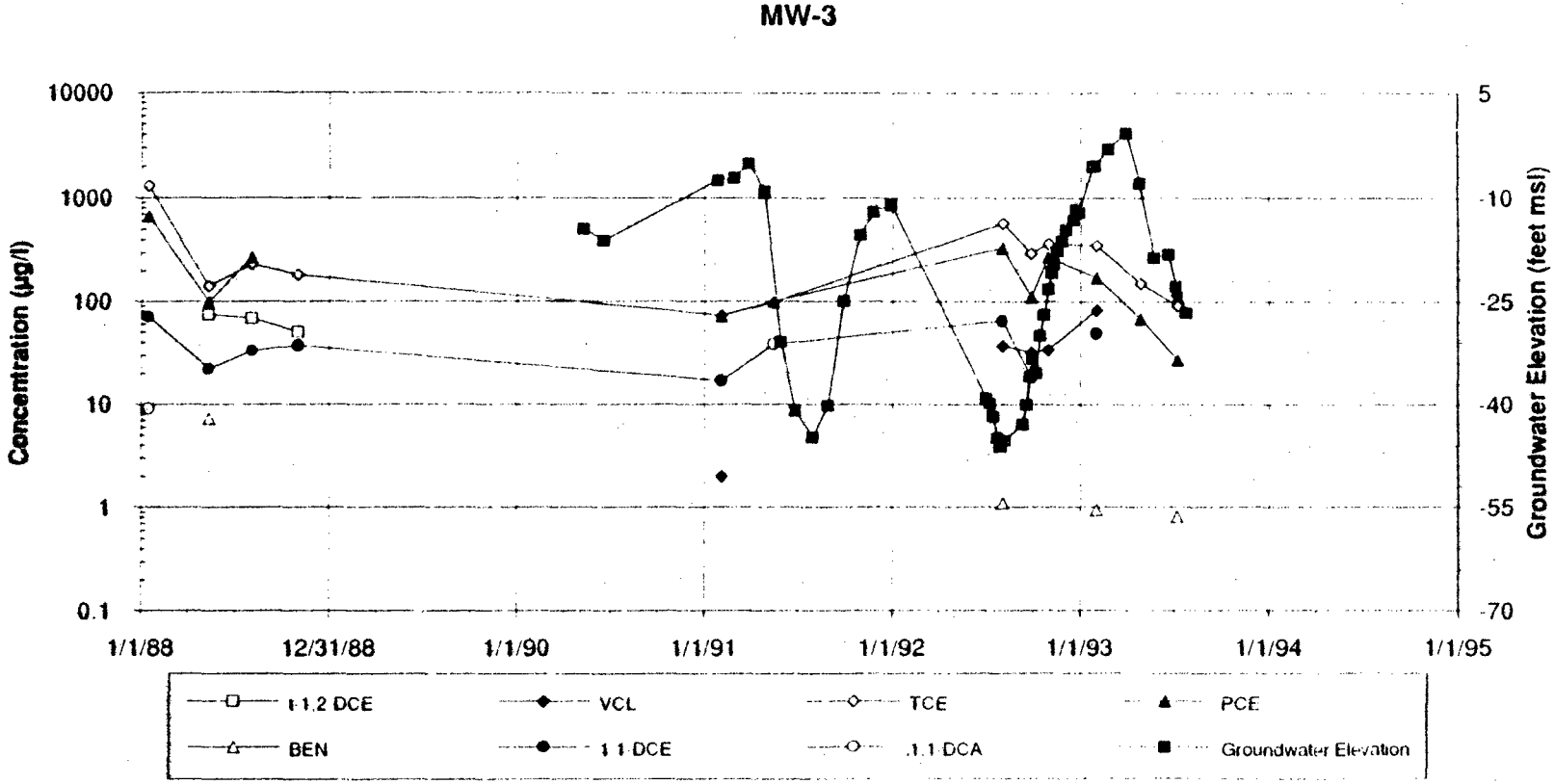

G:\users\data\emr\davislog\MW-3LOG.XLC

Note
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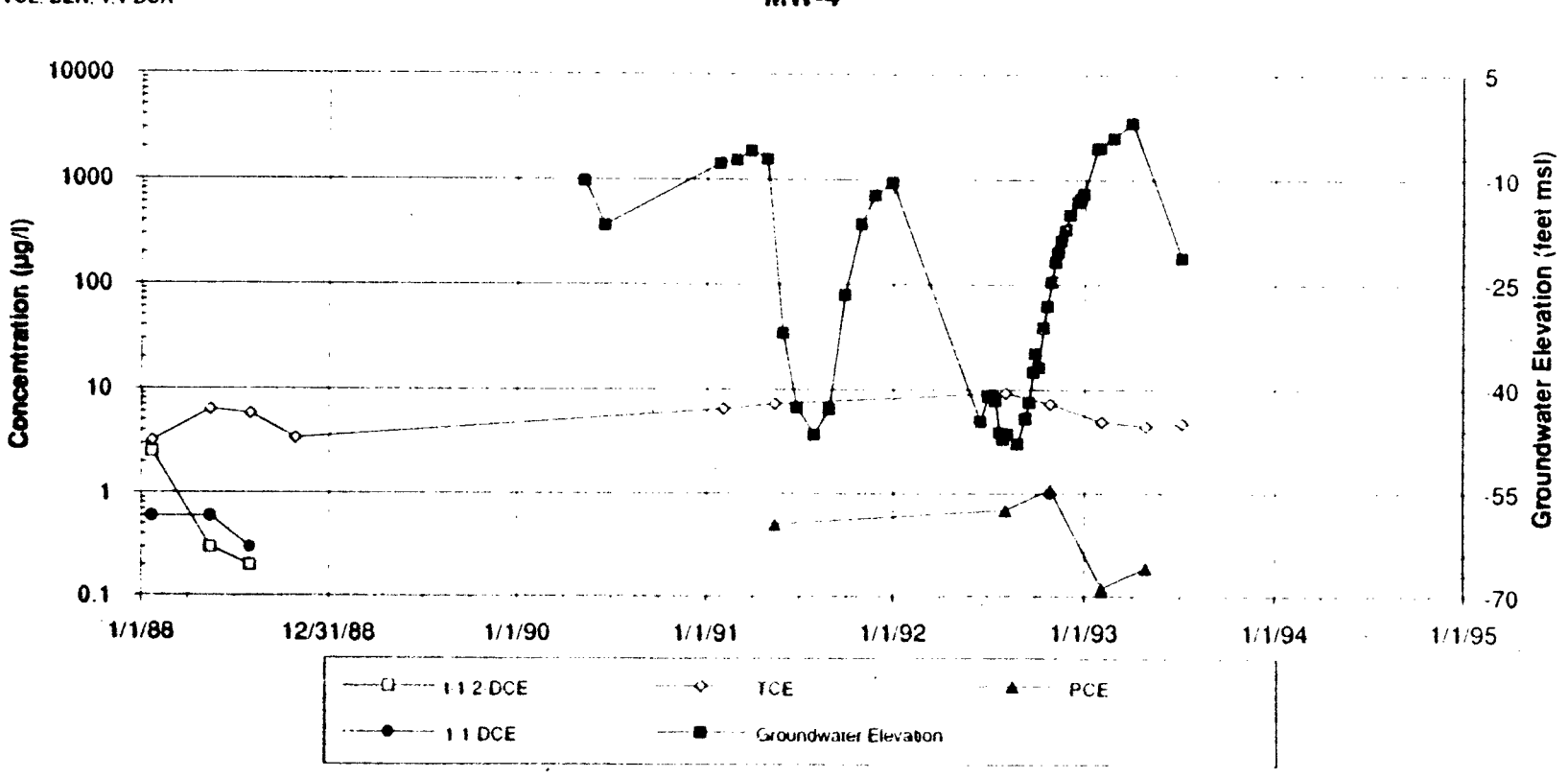
VCL, BEN, 1,1-DCA



G:\users\da\emr davislog\MW-4LOG.XLC

Note
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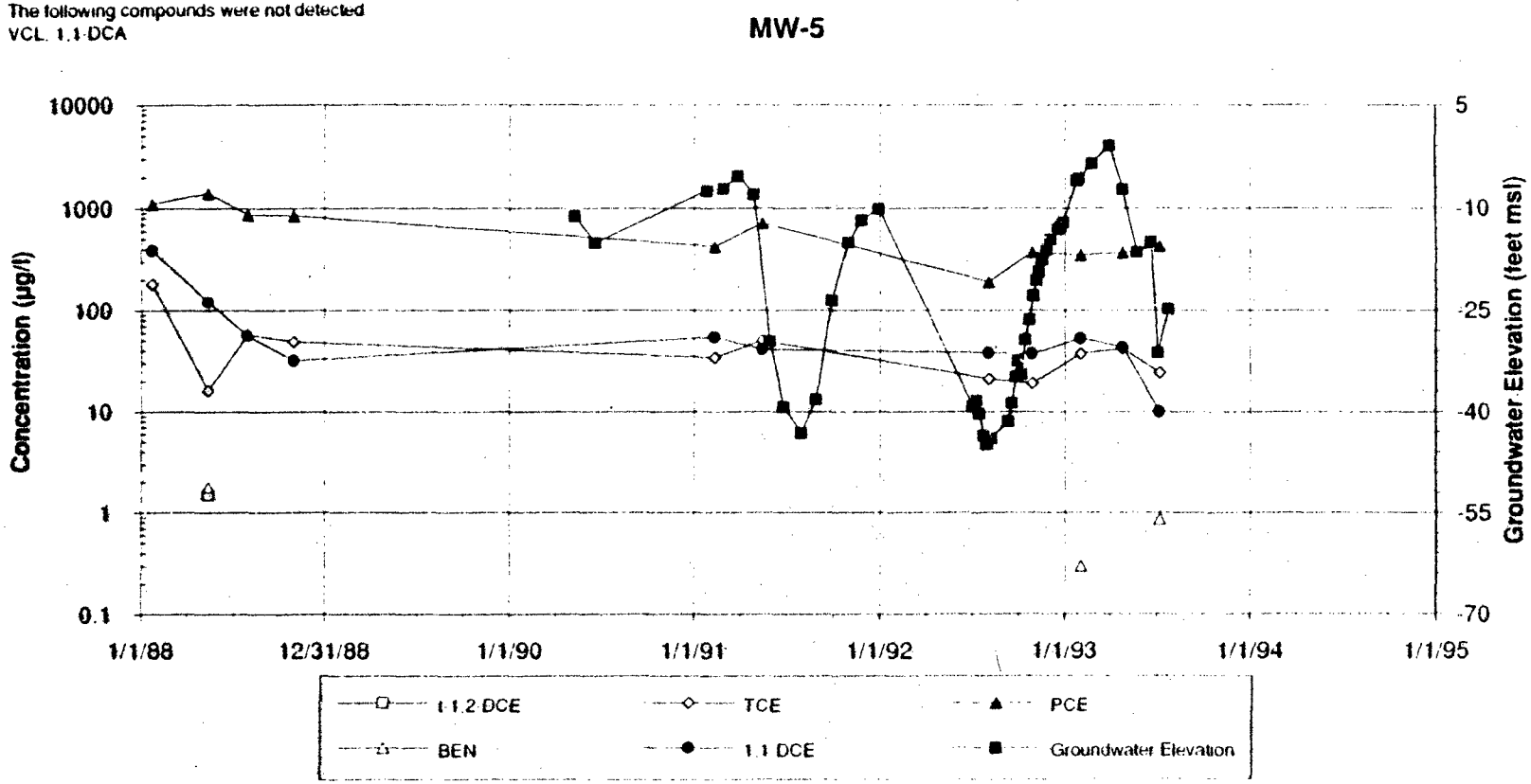

G:\users\da-emr\davislog\MW 5LOG.XLC

Note:
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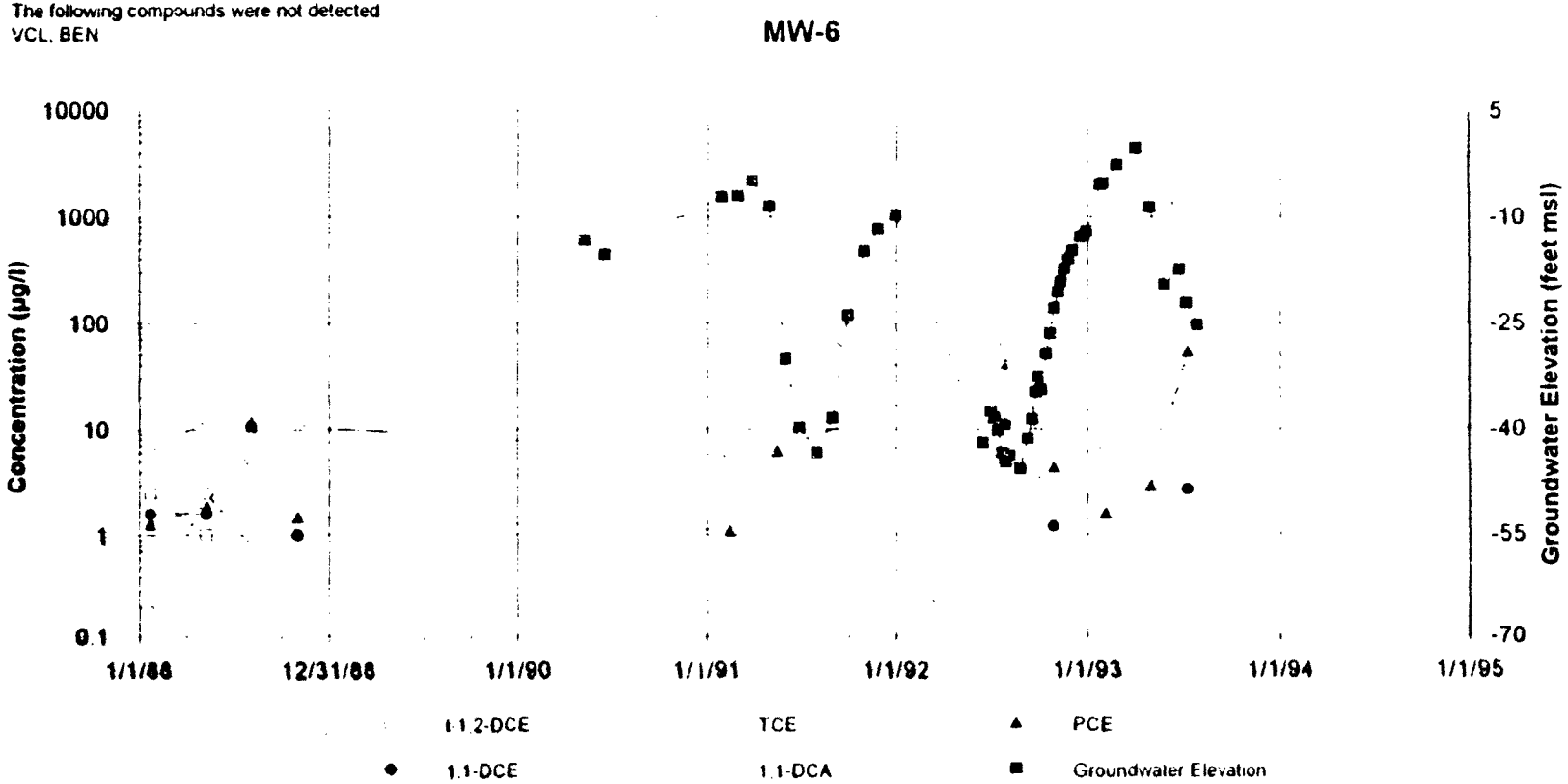

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Note
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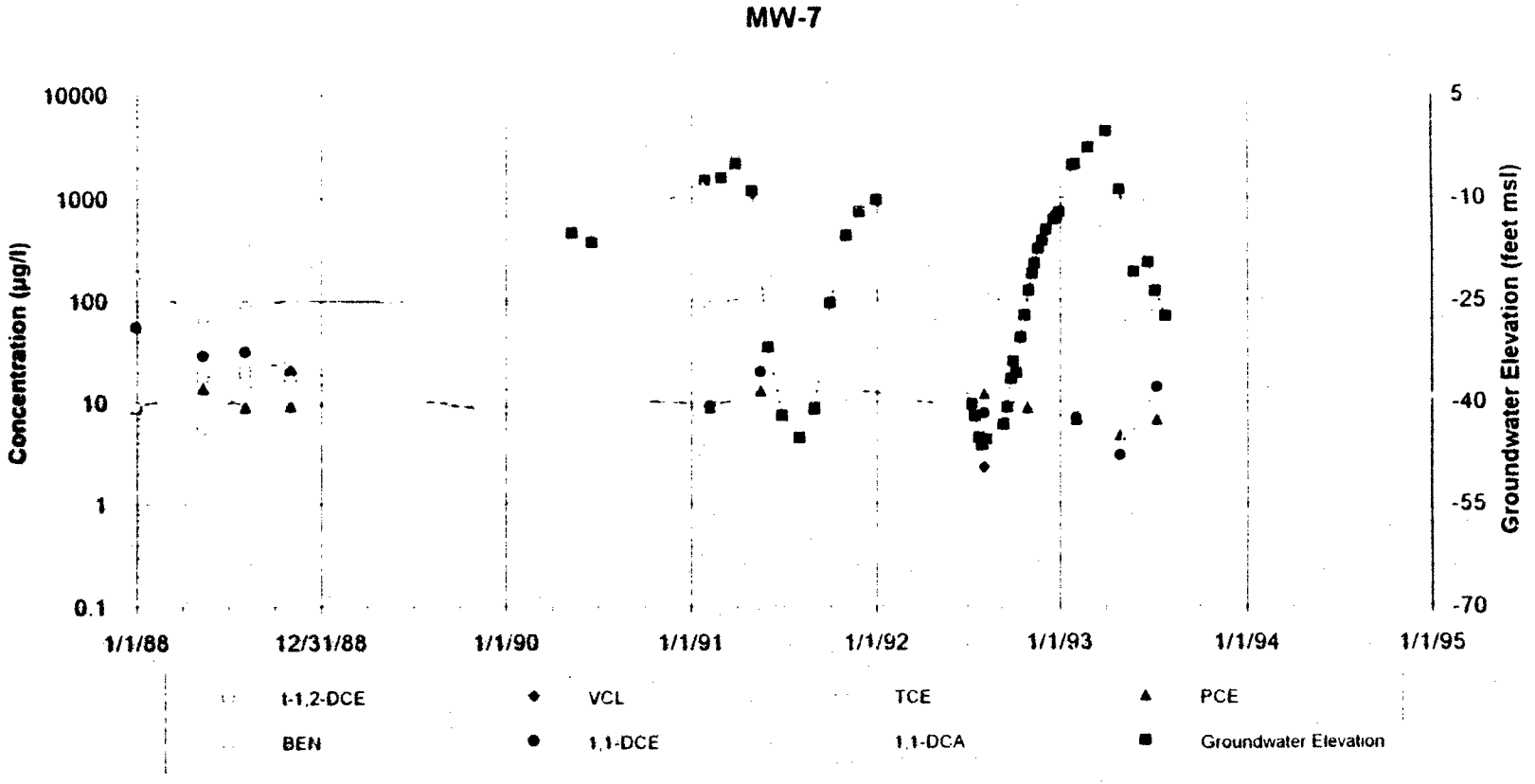

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Note:
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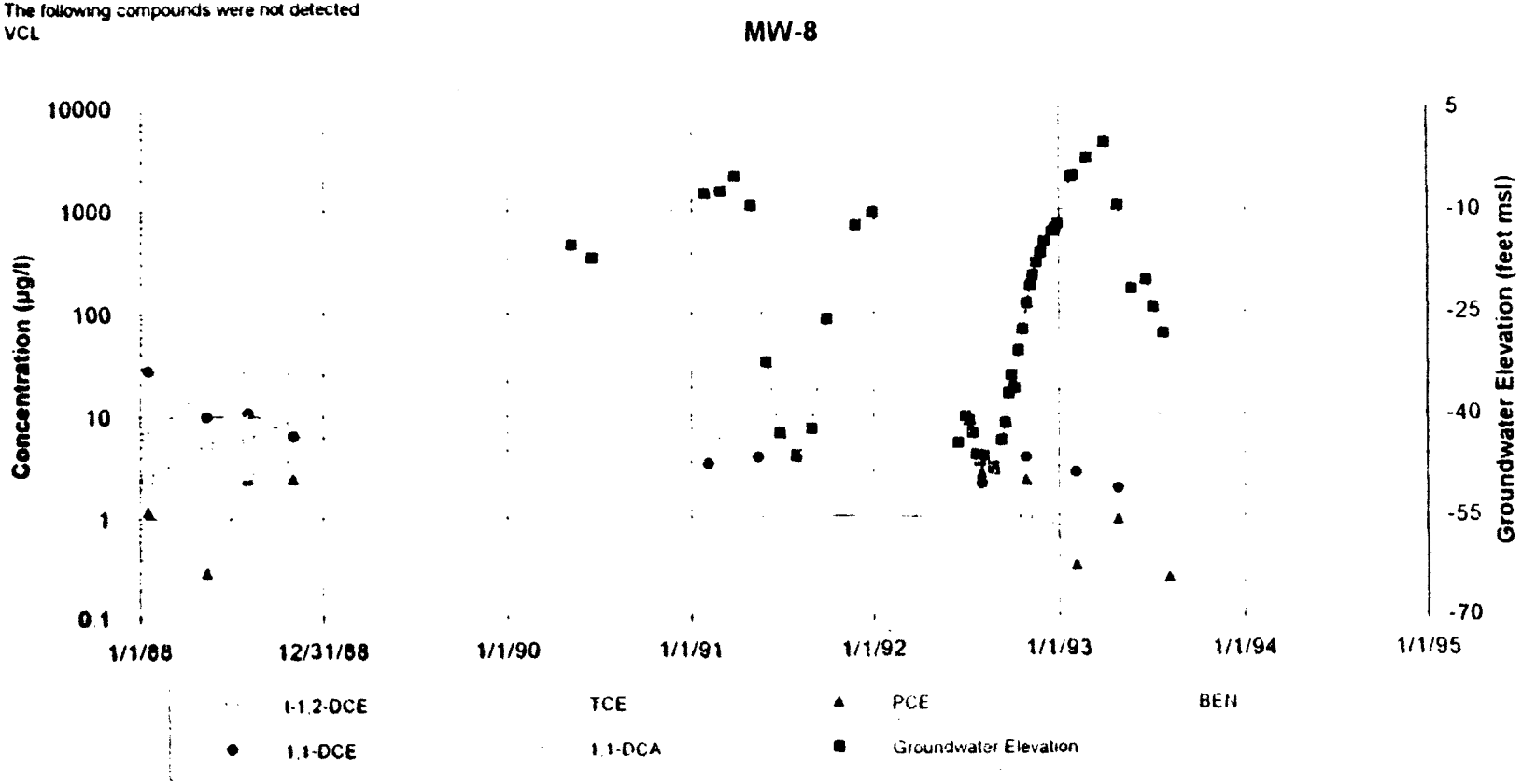

G:\users\da\emr\da\slog\MW-8LOG.XLC

Note
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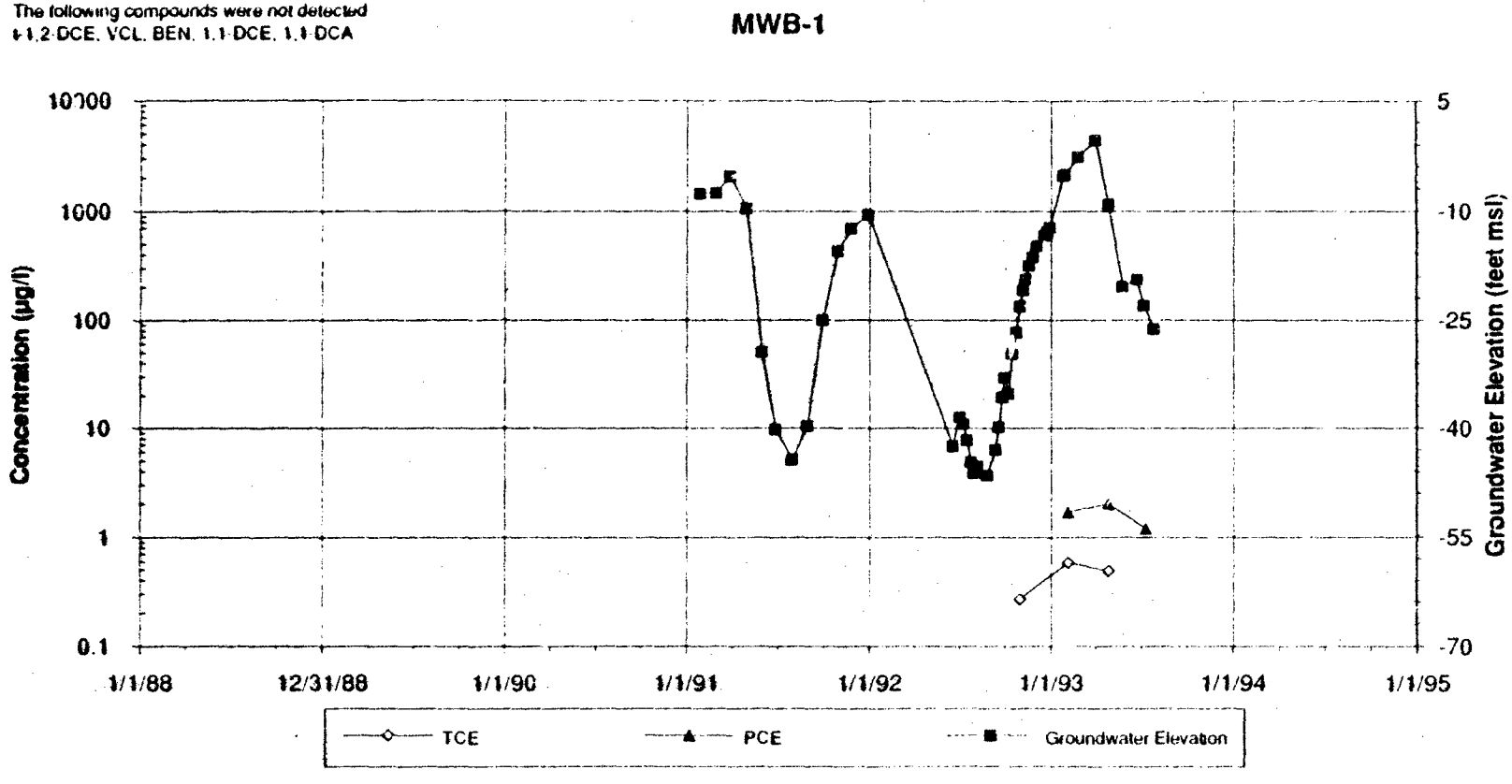
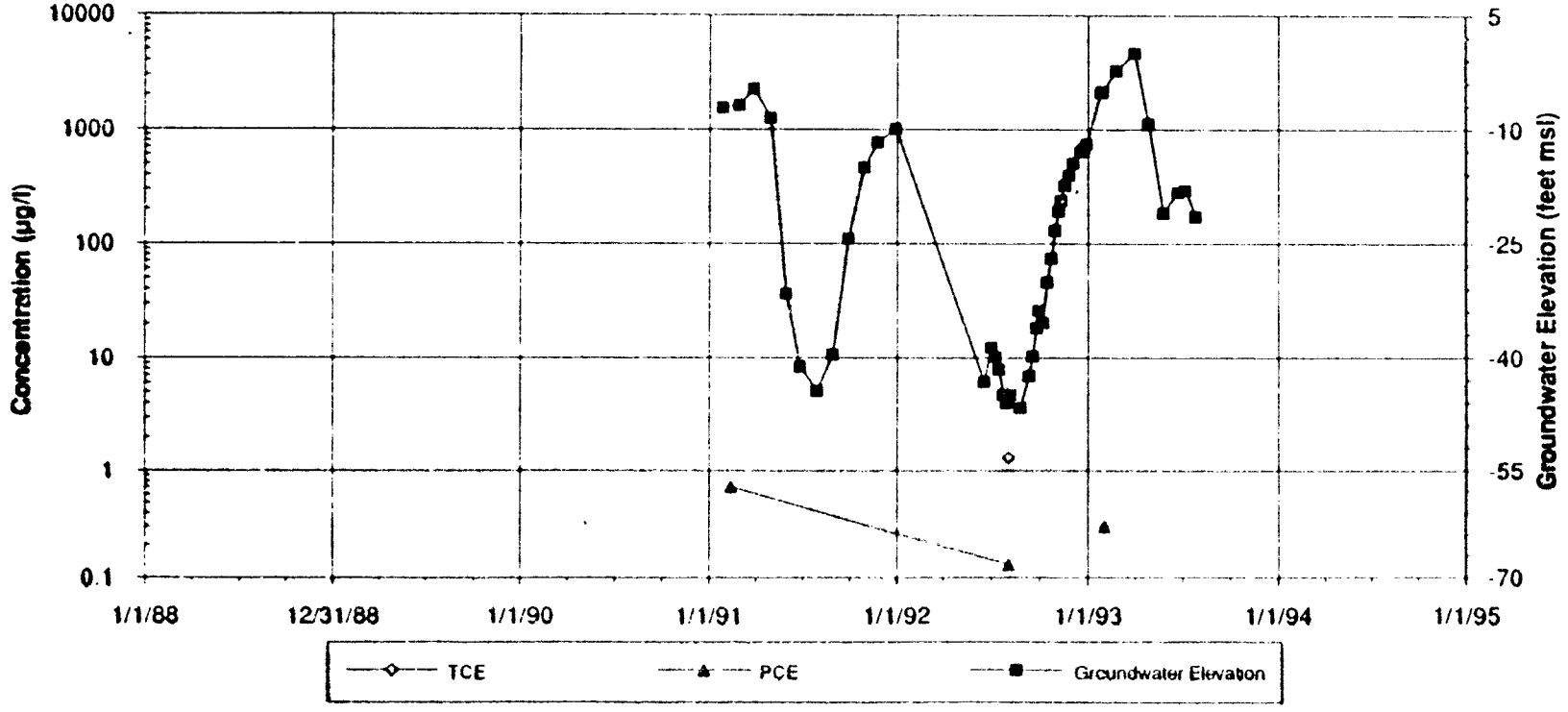
The following compounds were not detected
t-1,2-DCE, VCL, BEN, 1,1-DCE, 1,1-DCA



G:\users\da\emr\davislog MWB-1LG.XLC

Note:
Non detects for compounds will appear as a break in the data series
The following compounds were not detected:
t-1,2-DCE, VCL, BEN, 1,1-DCE, 1,1-DCA

MWB-4



G:\users\da\emr\davislog\MWB-4LOG.XLC

Note
Non detects for compounds will appear as a break in the data series
The following compounds were not detected
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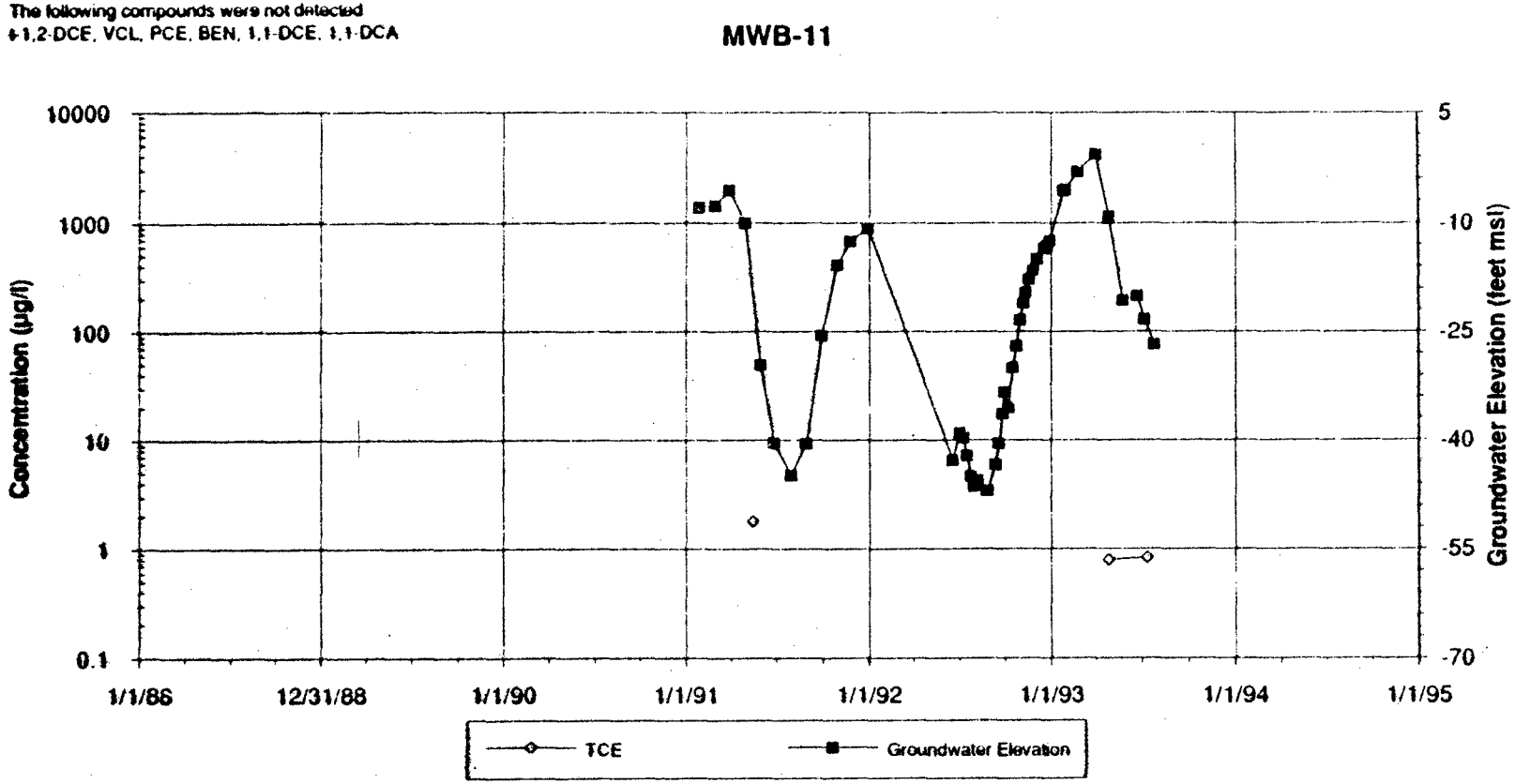

G:\users\da\emr\davis\log\MWB-11LG.XLC

Note
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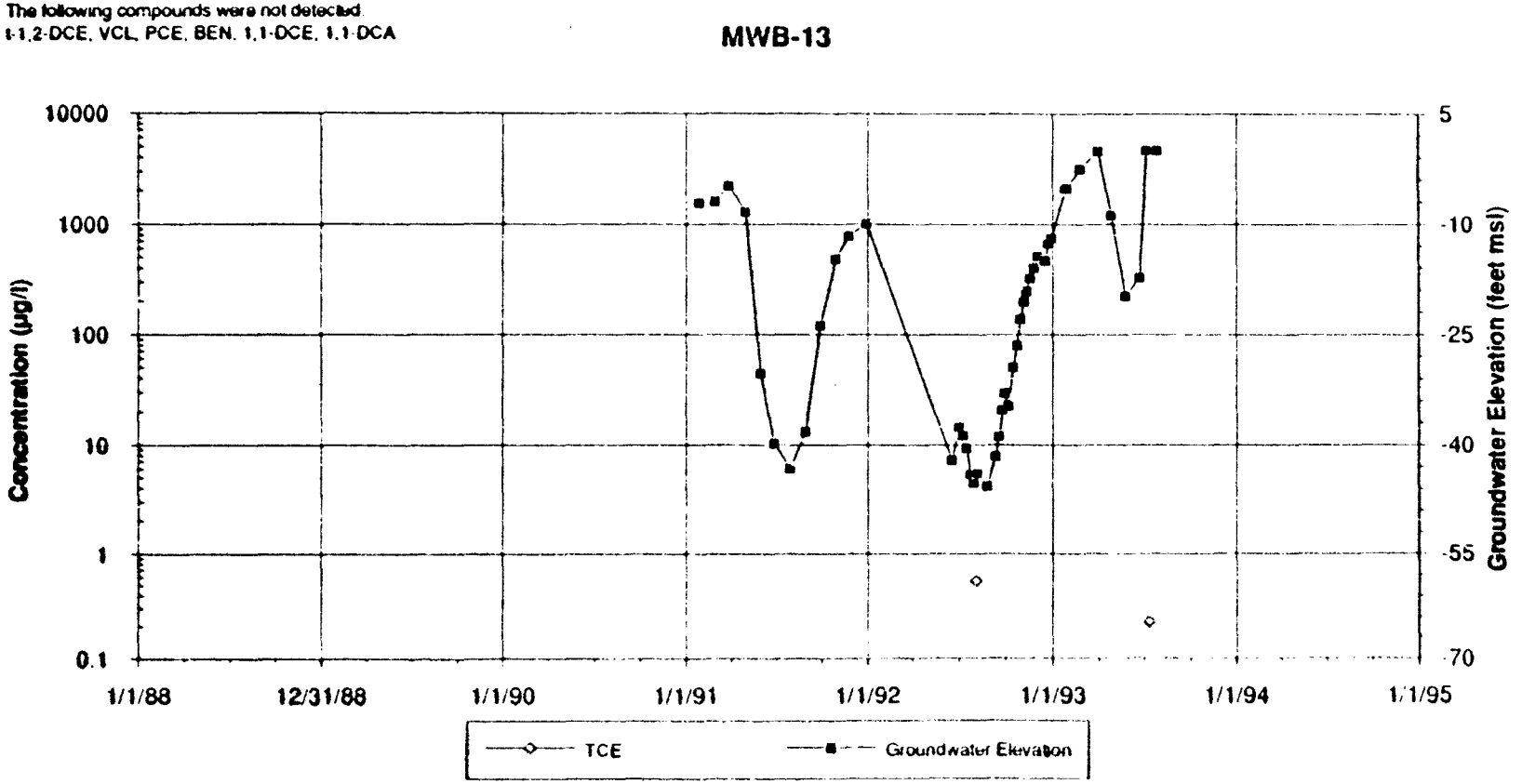

G users da emr davislog MWB-13LG XLC

Note:
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The following compounds were not detected
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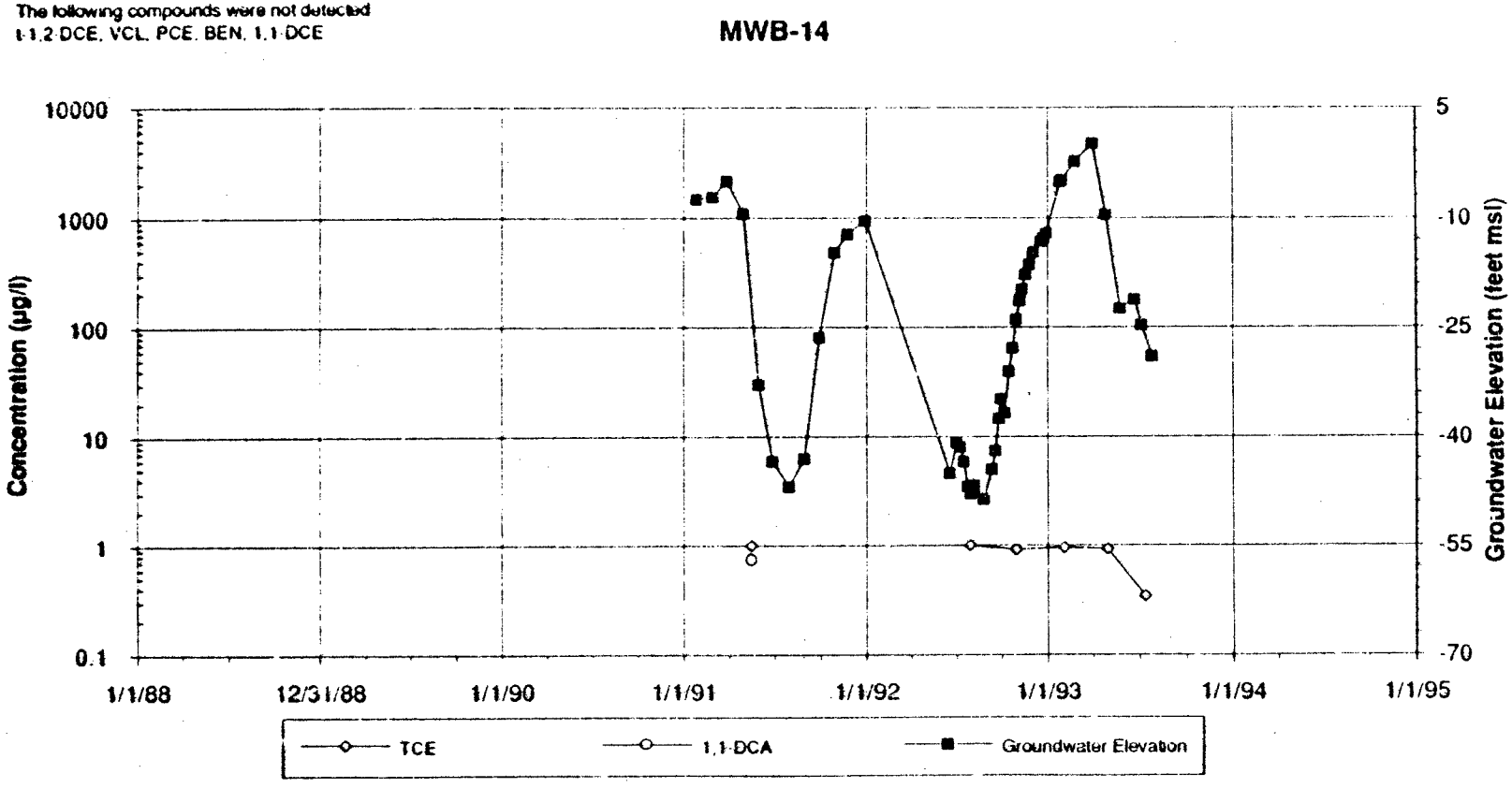

G:\users\da.emr\davislog\MWB-14LG.XLC

Note
Non detects for compounds will appear as a break in the data series
The following compounds were not detected
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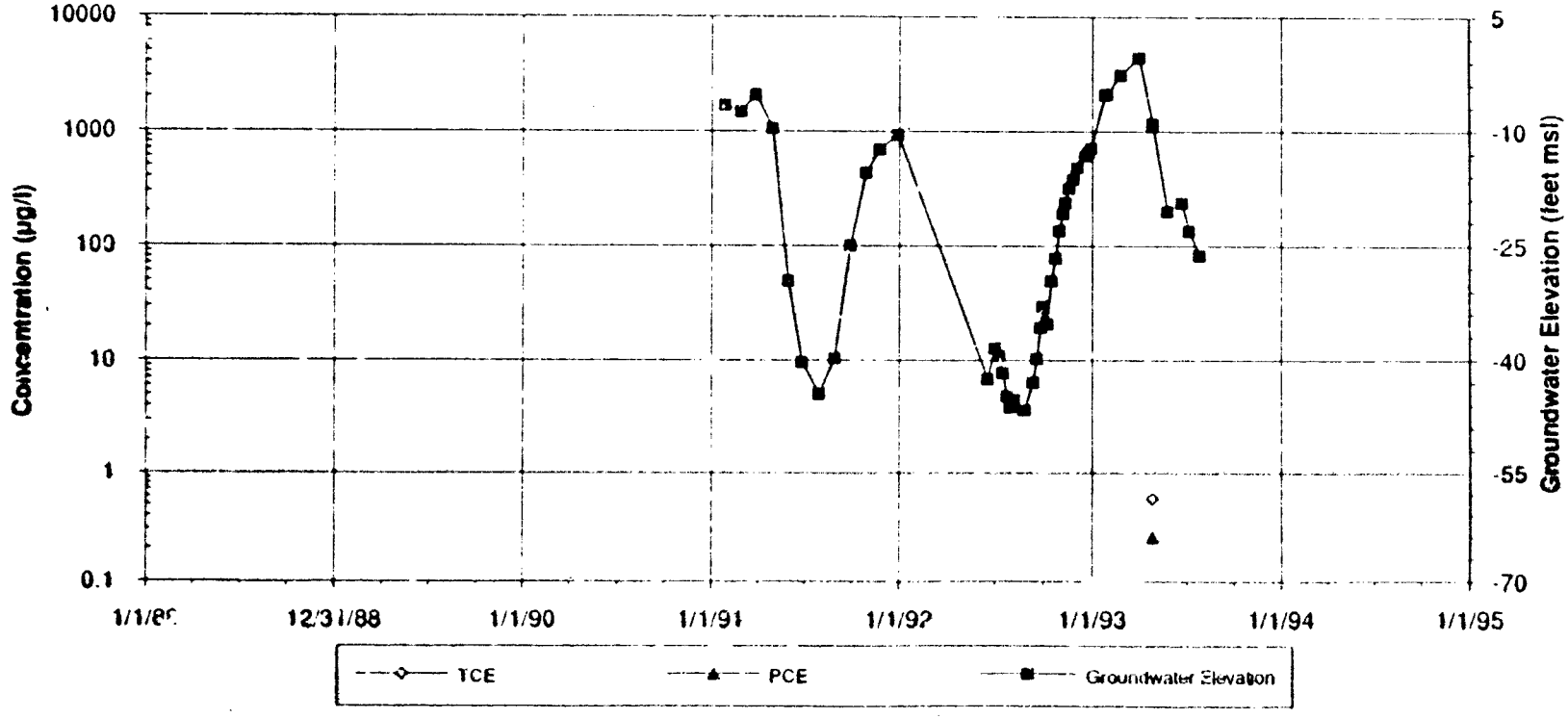
MWC-1



G:\users\da em\davislog\MWC-1LOG.XLC

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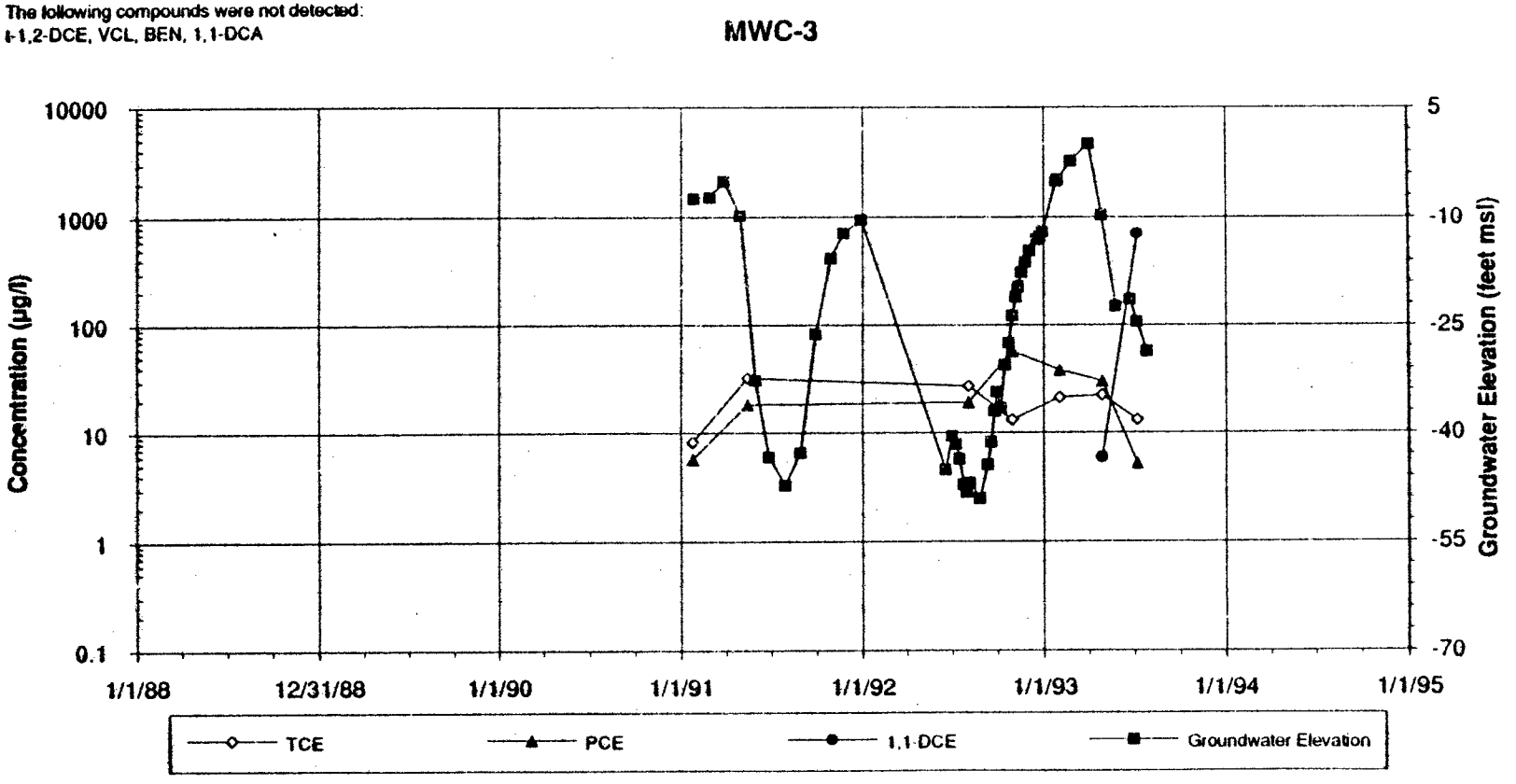

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Note:
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The following compounds were not detected:
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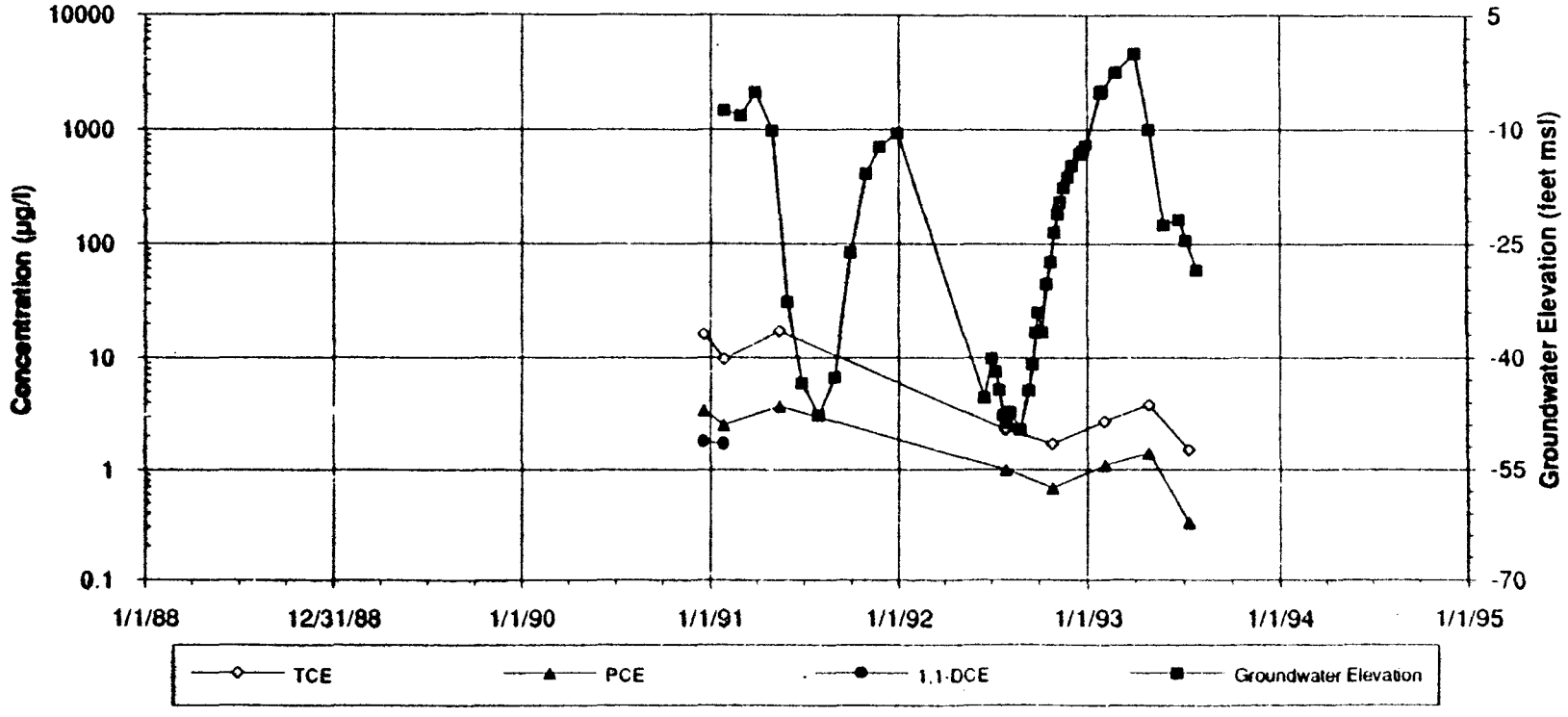
MWC-12



G:\users\da\emr\davislog\MWC-12LG.XLC

Note:
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The following compounds were not detected:
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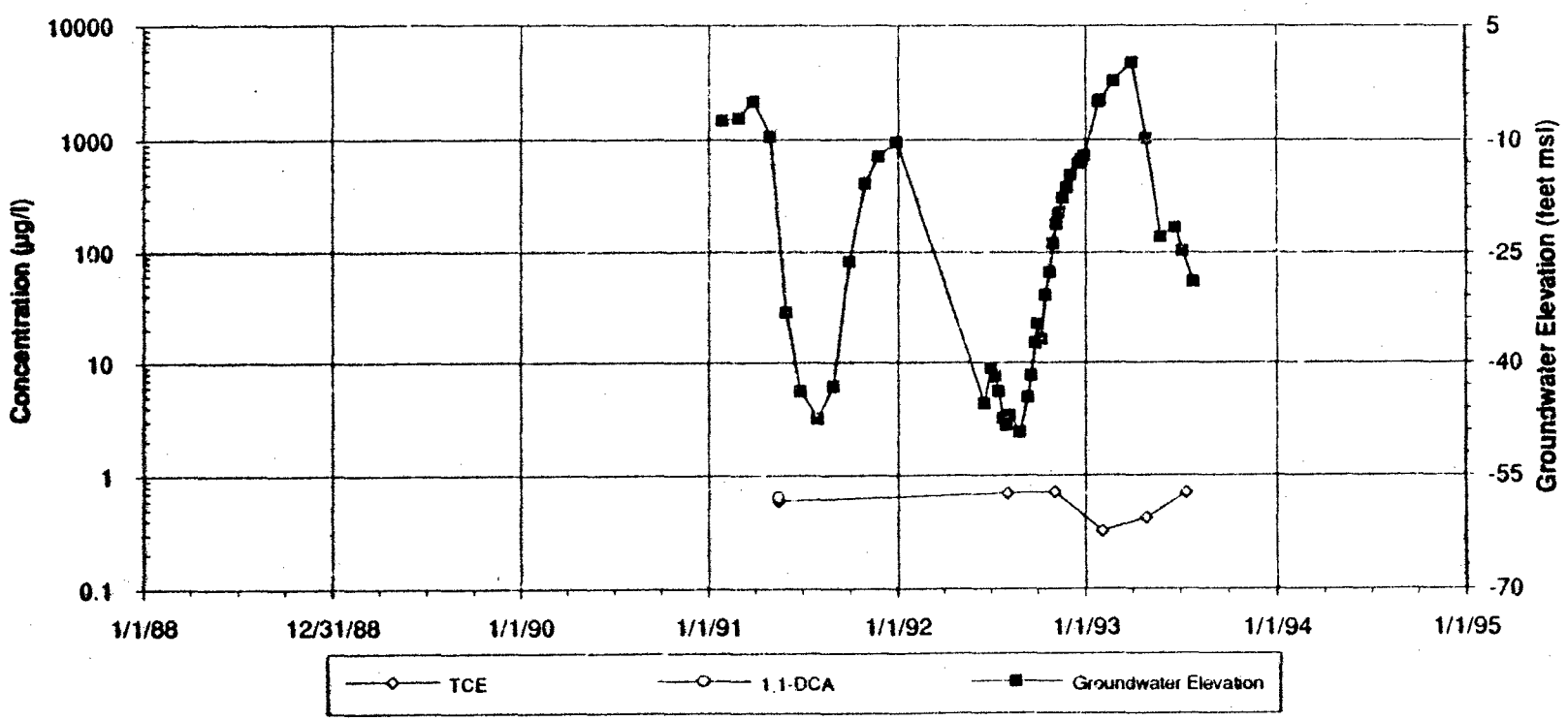
MWC-14



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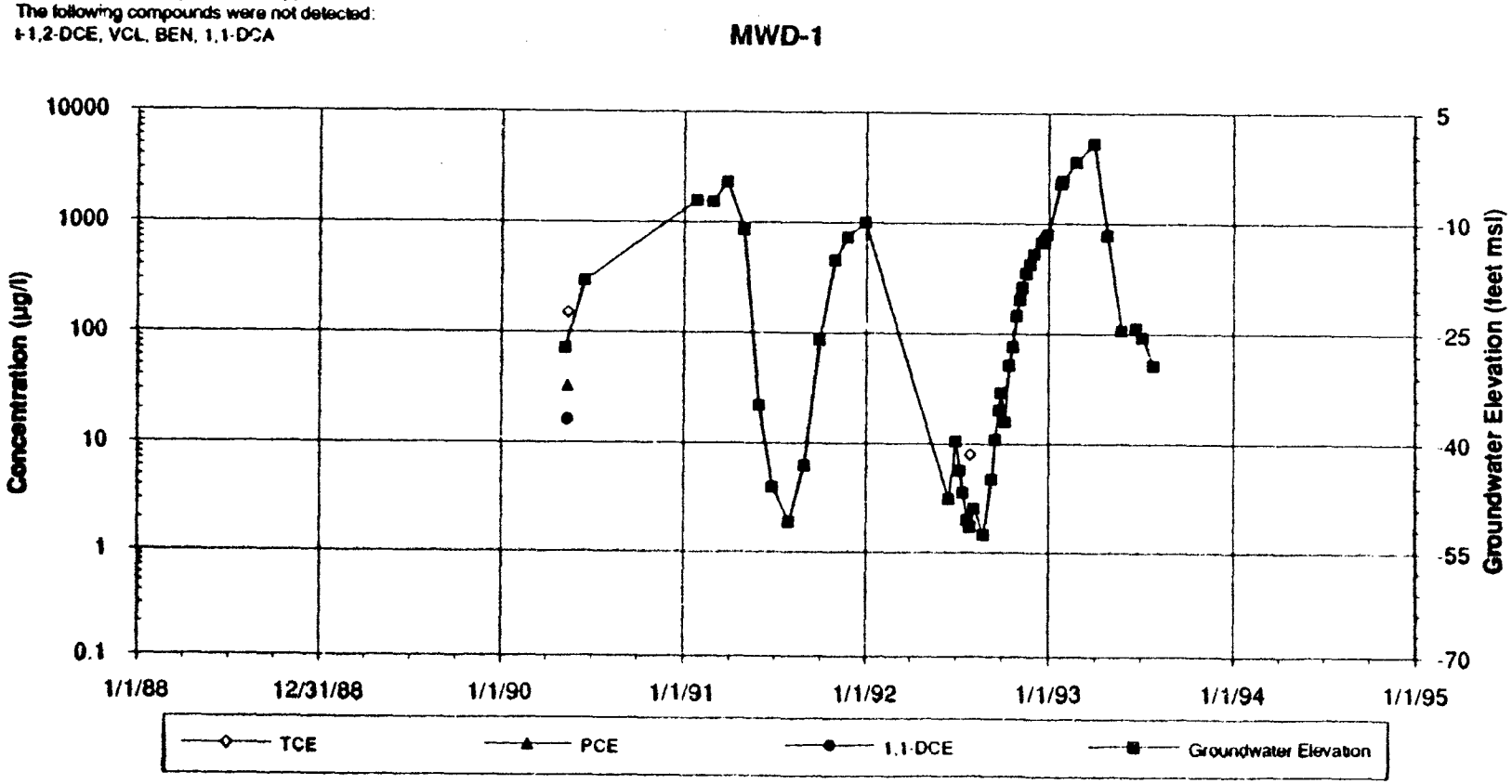

Note:
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The following compounds were not detected:
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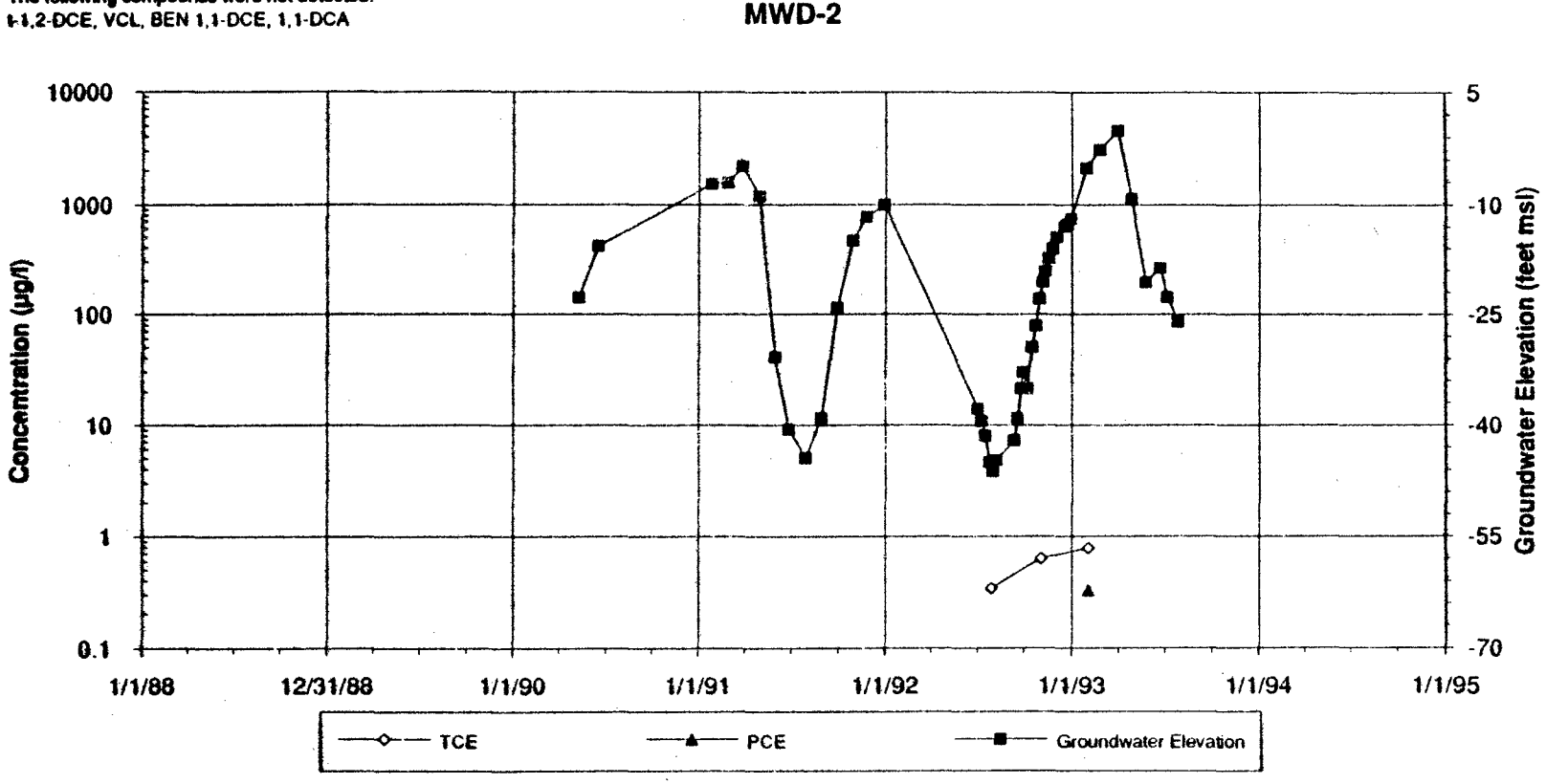

G:\users\da\emr\davislog\MWD-2LOG.XLC

Note:
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The following compounds were not detected:
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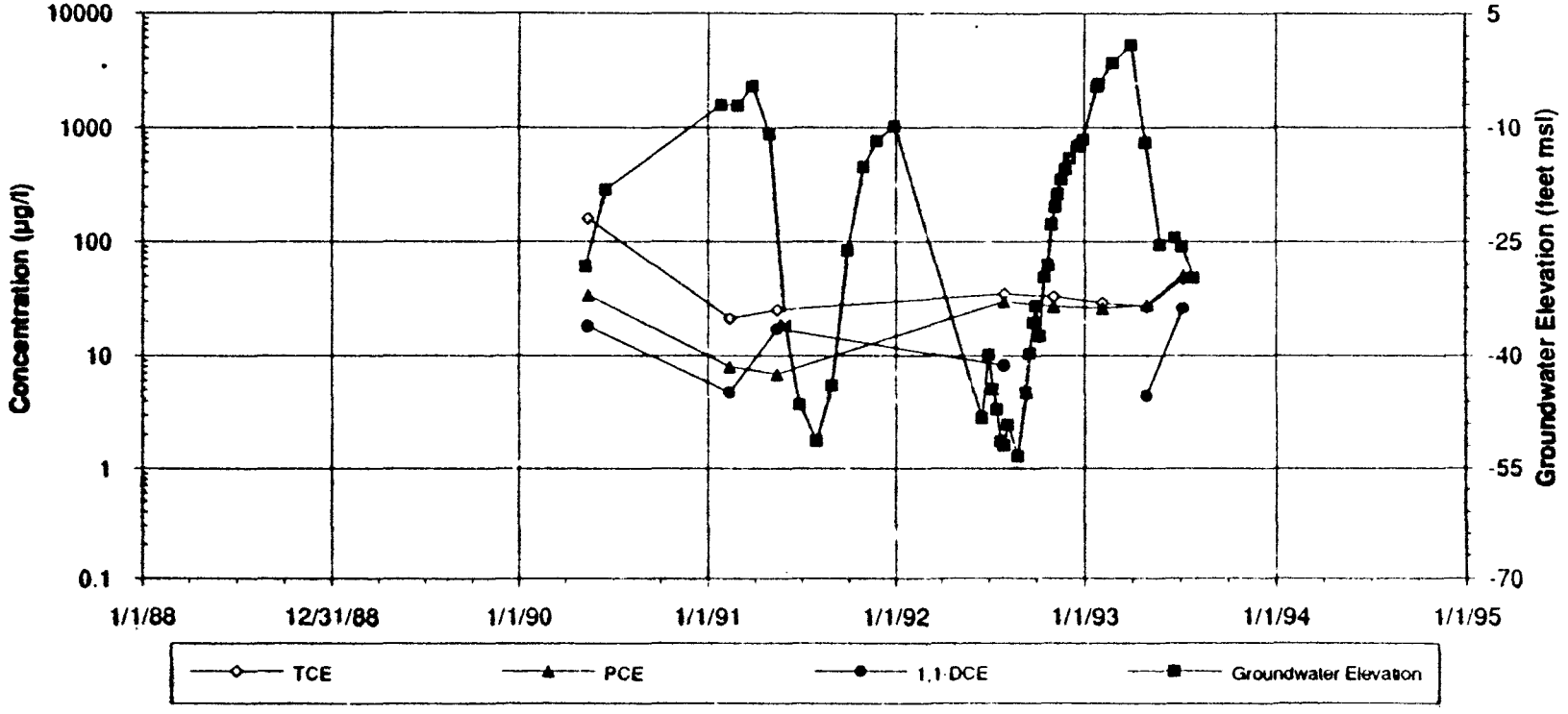

G:\users\da\emr\davislog\MWD-3LOG.XLC

Note:
Non detects for compounds will appear as a break in the data series.
The following compounds were not detected:
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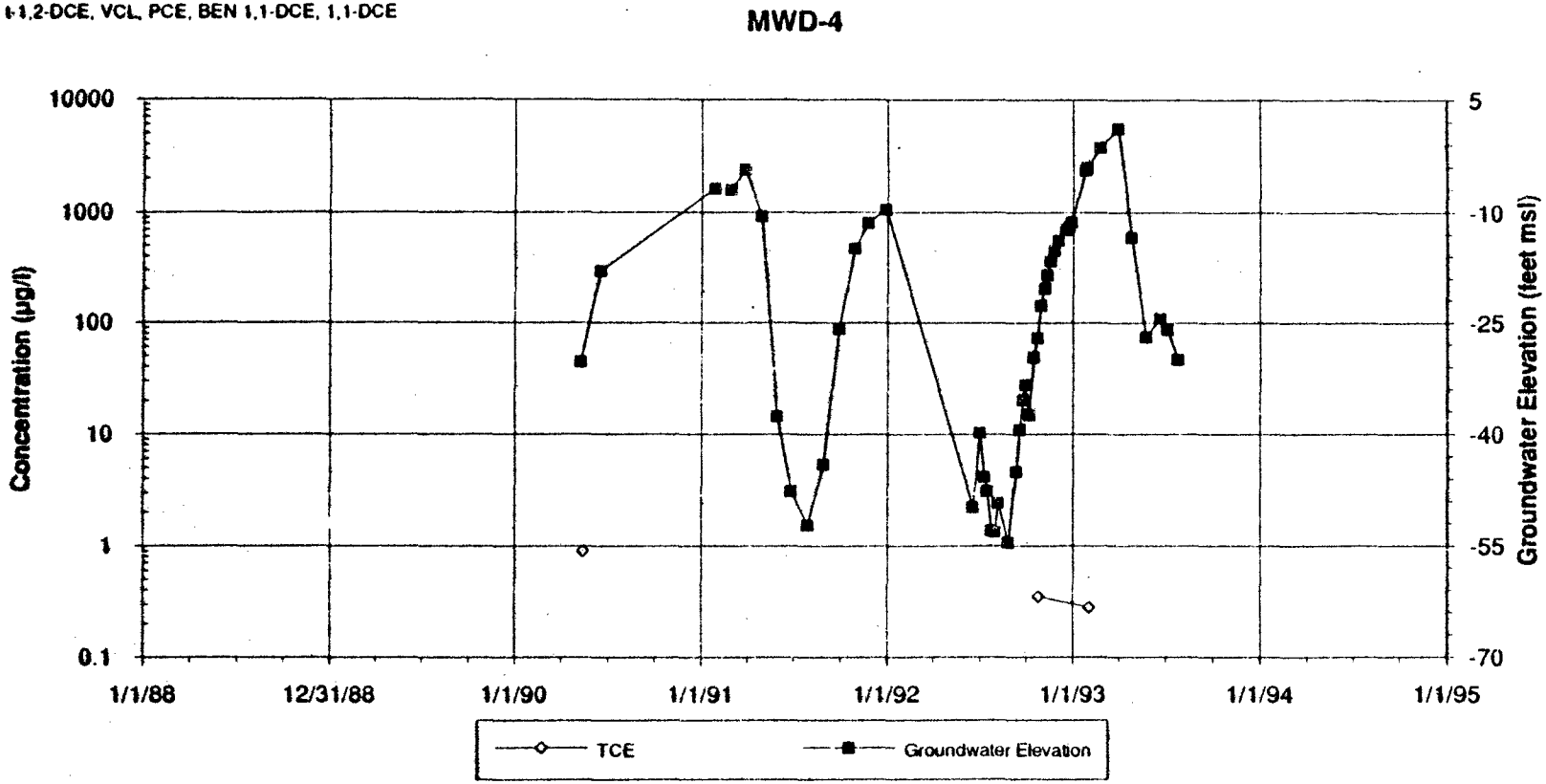
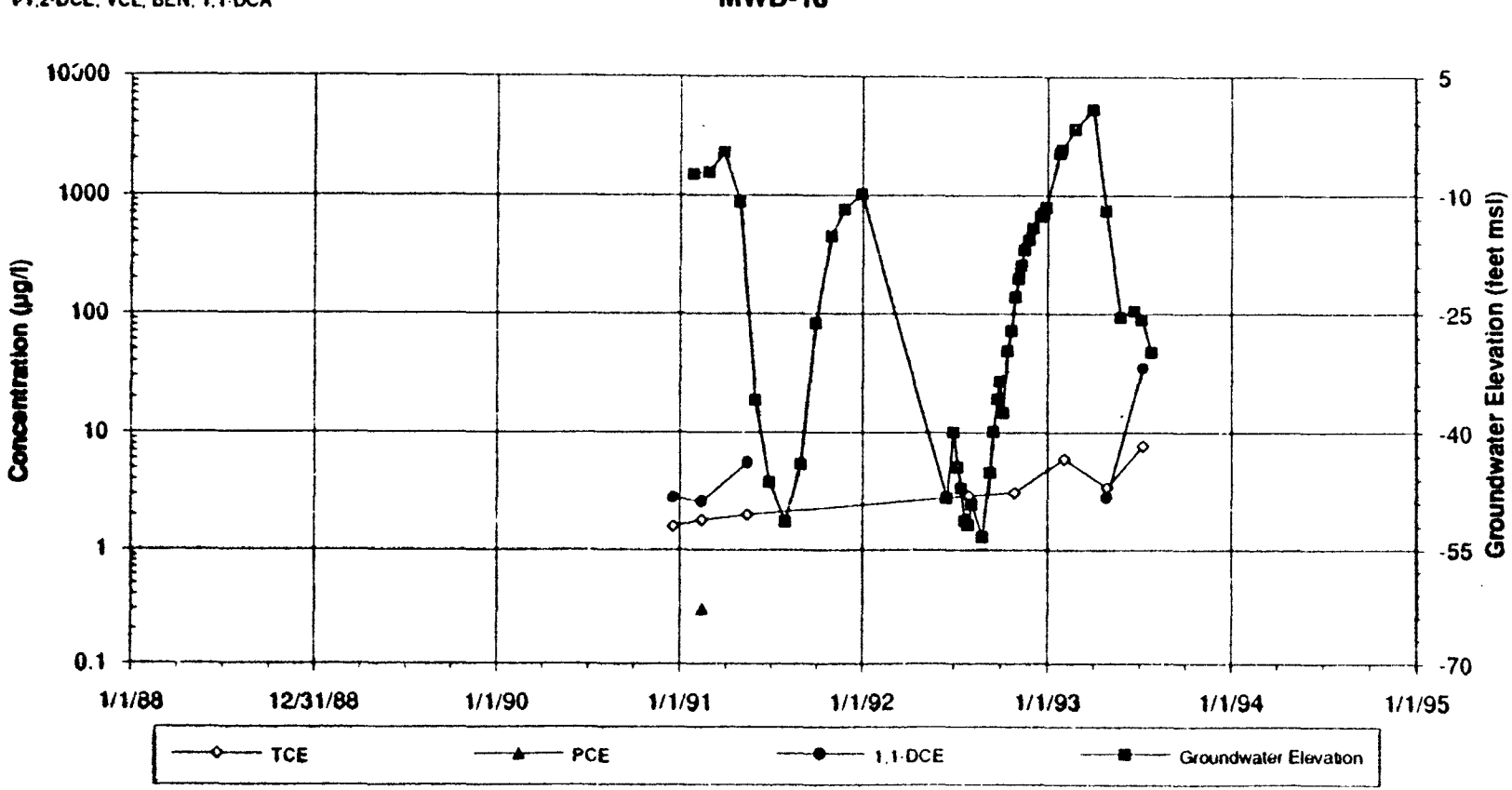


G:\users\da\emr\davislog\MWD-4LOG.XLC

Note:
Non detects for compounds will appear as a break in the data series
The following compounds were not detected:
t-1,2-DCE, VCL, BEN, 1,1-DCA



G:\users\da\emr\davislog\MWD-10LG.XLC

Note:
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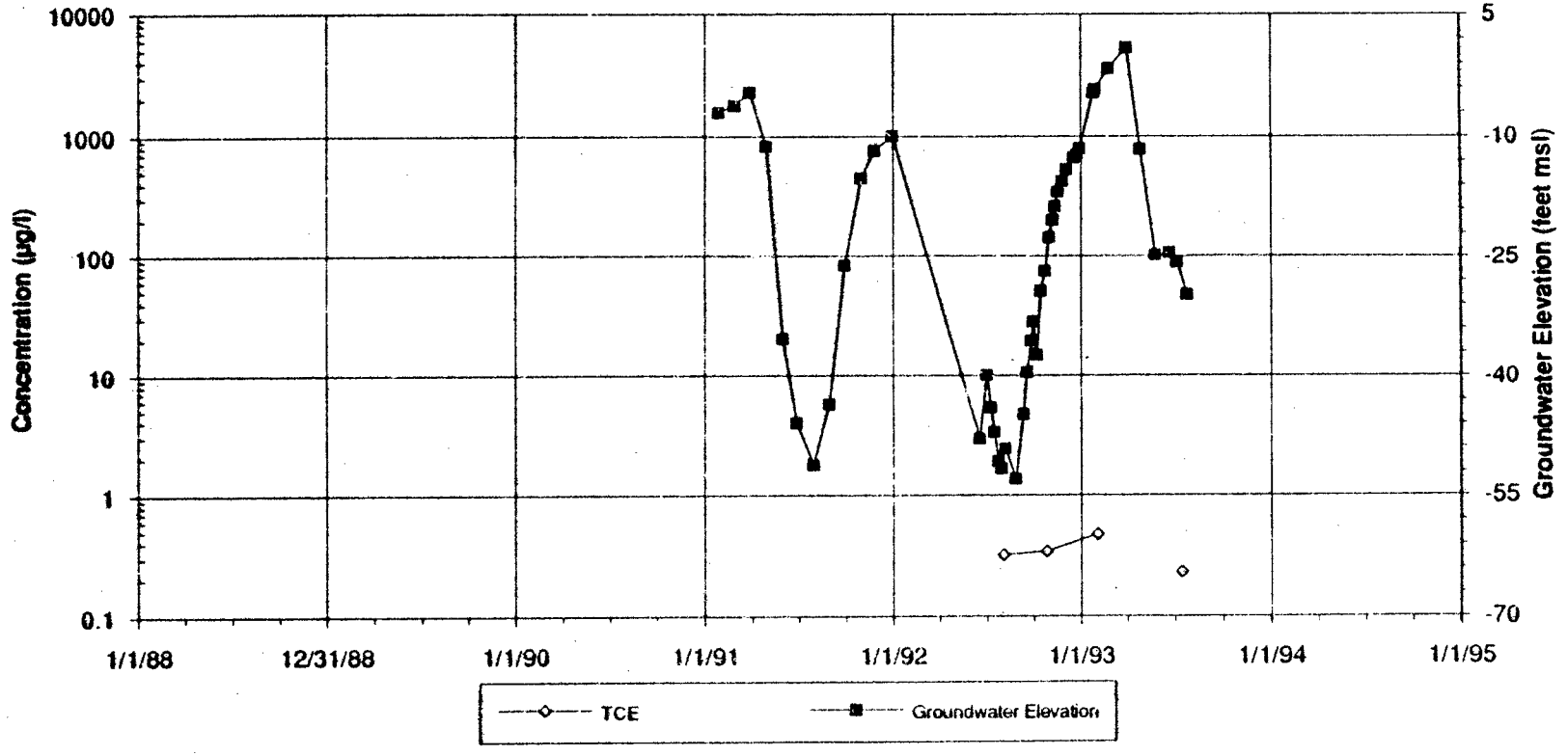

Note:
Non detects for compounds will appear as a break in the data series.
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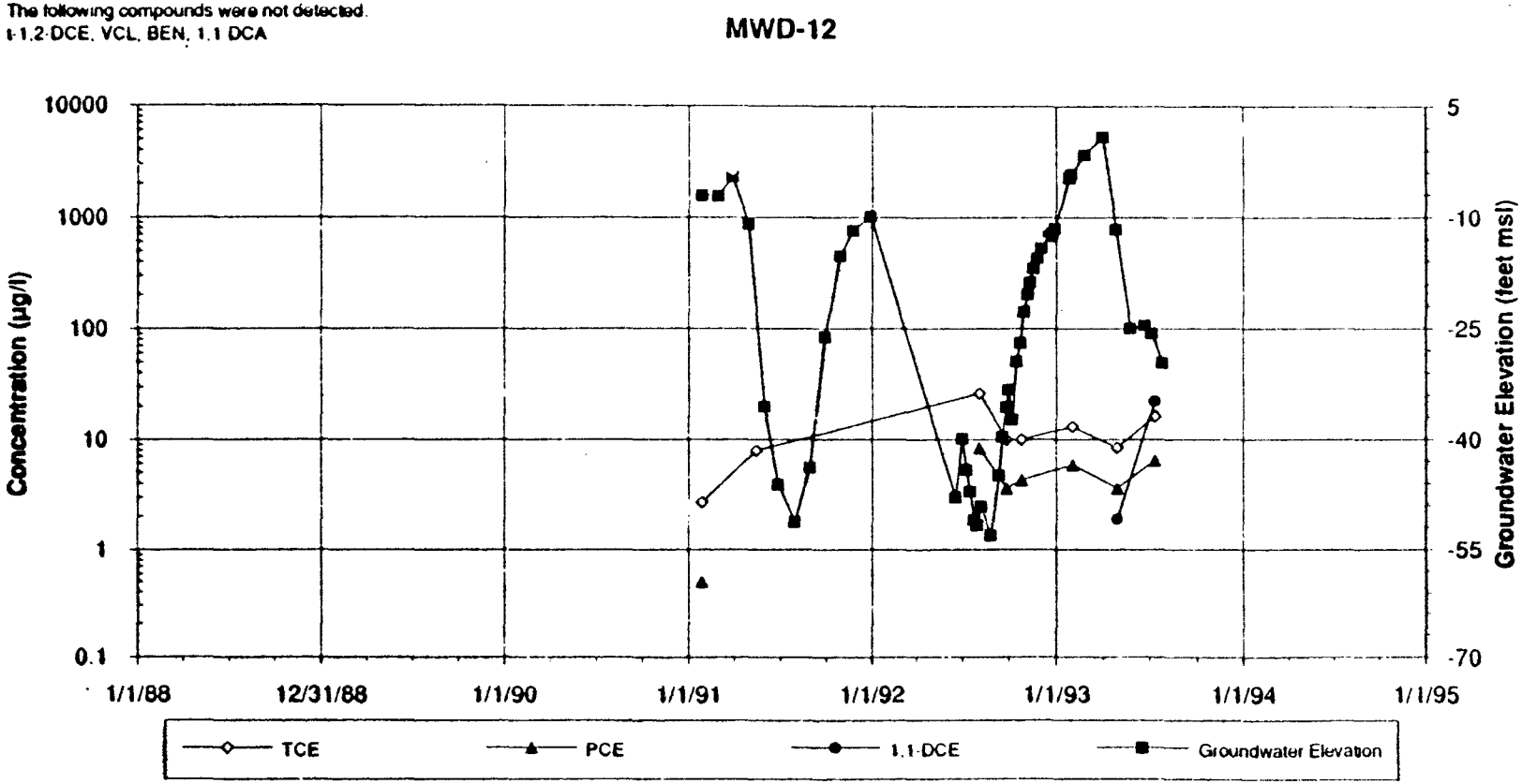

G:\users\da\emr\davislog\MWD-12LG XLC

Note:
Non detects for compounds will appear as a break in the data series.
The following compounds were not detected:
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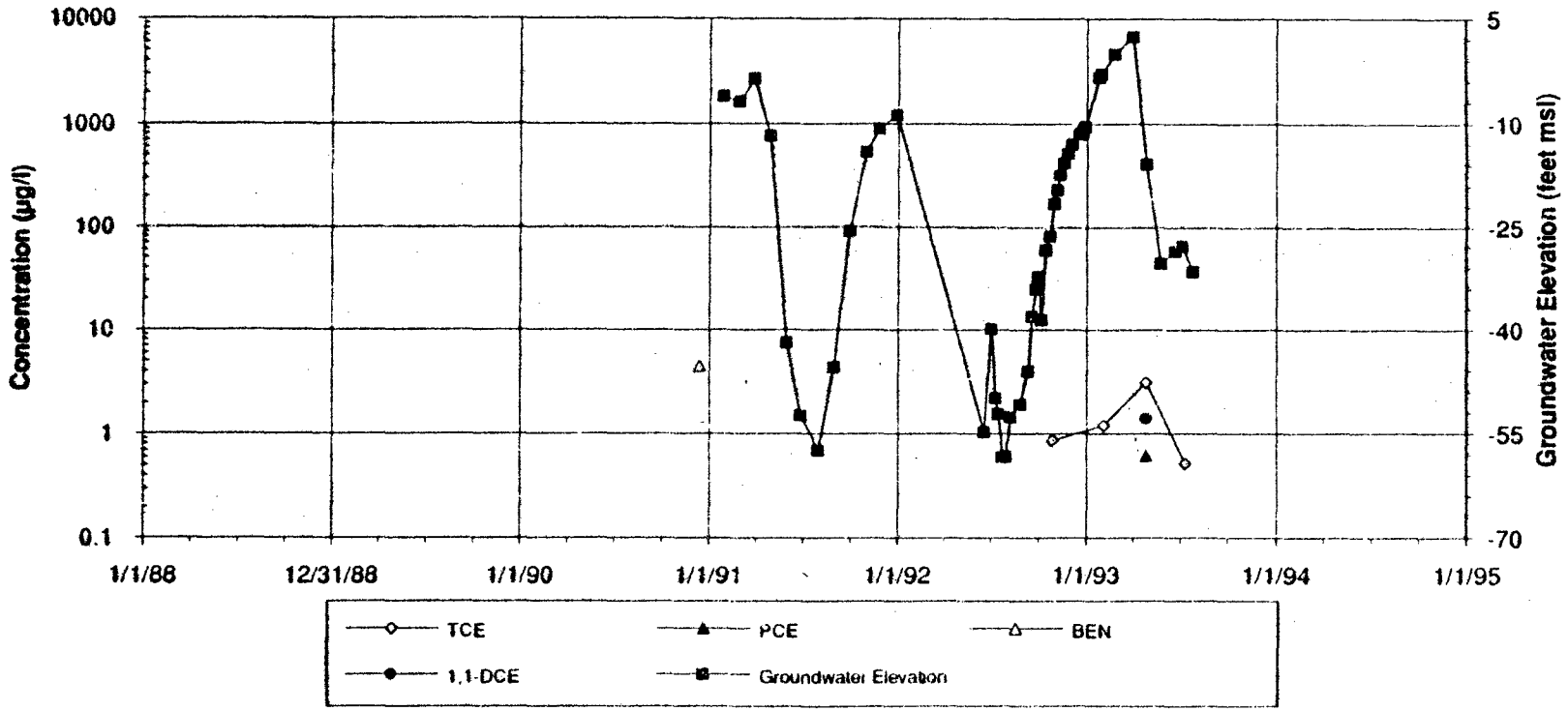
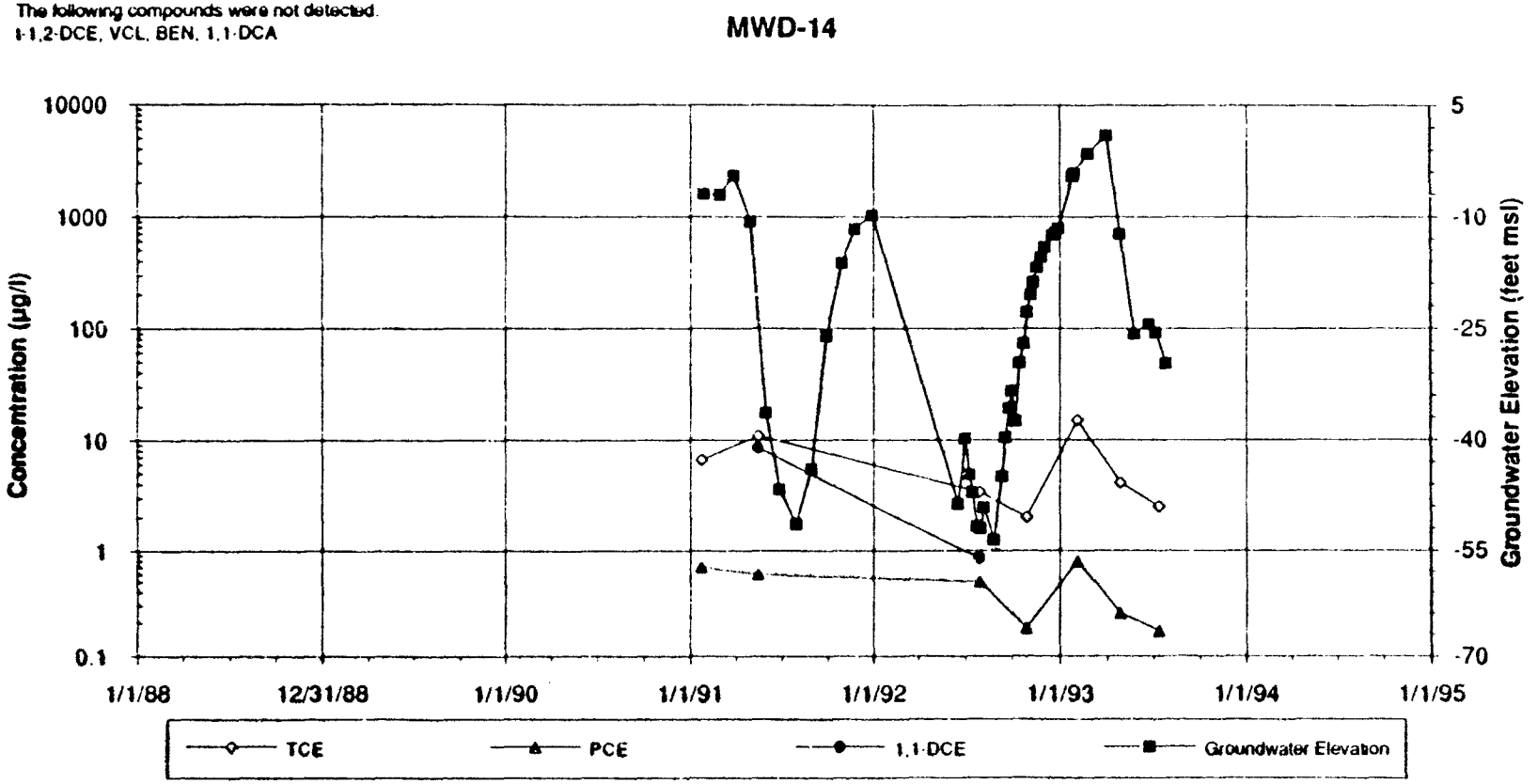


G:\users\davem\division\MWD-13LG.XLC

Note
Non detects for compounds will appear as a break in the data series
The following compounds were not detected.
t-1,2-DCE, VCL, BEN, 1,1-DCA



G:\users\da.emr\davislog\MWD-14LG.XLC

Note
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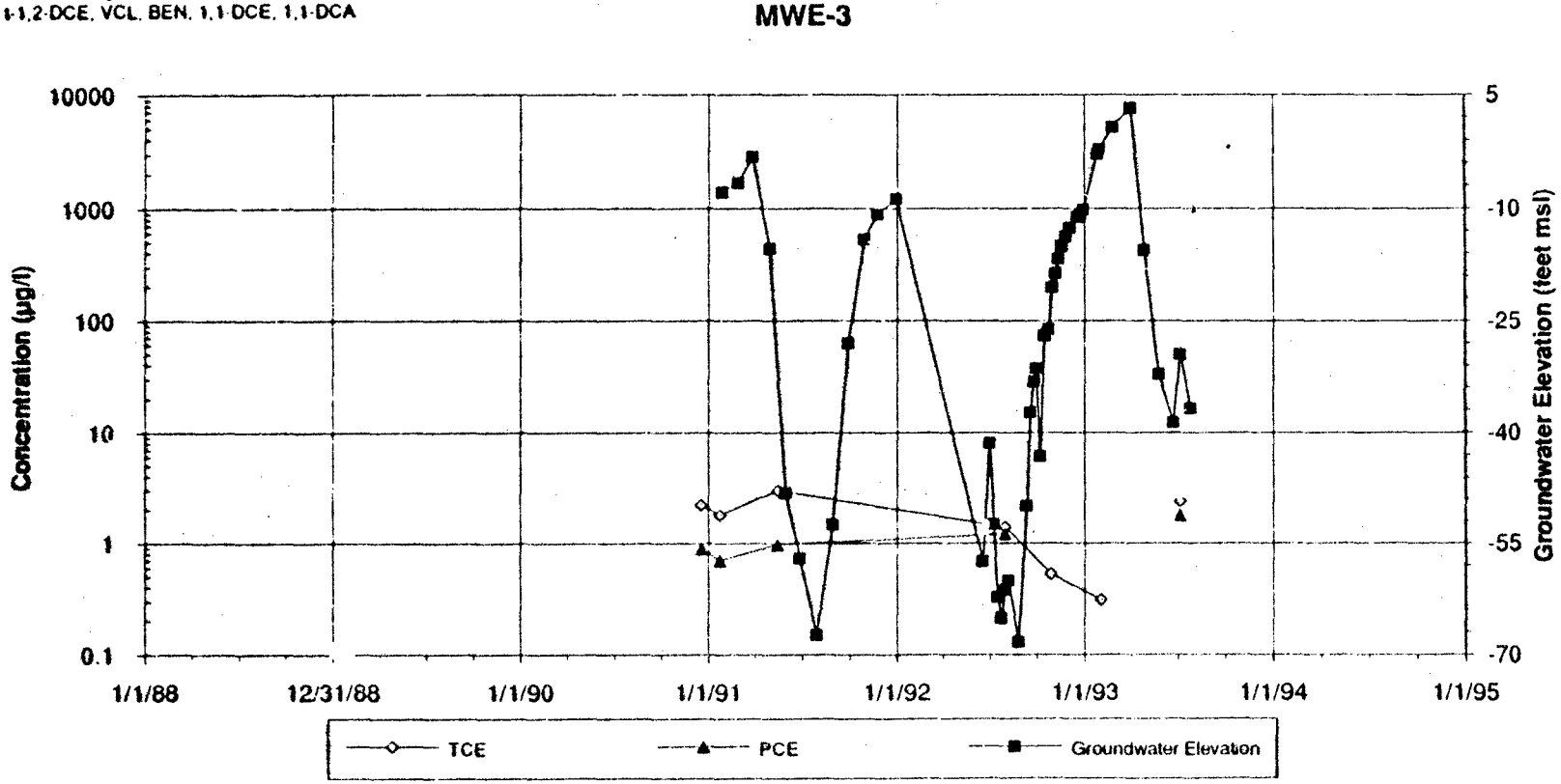
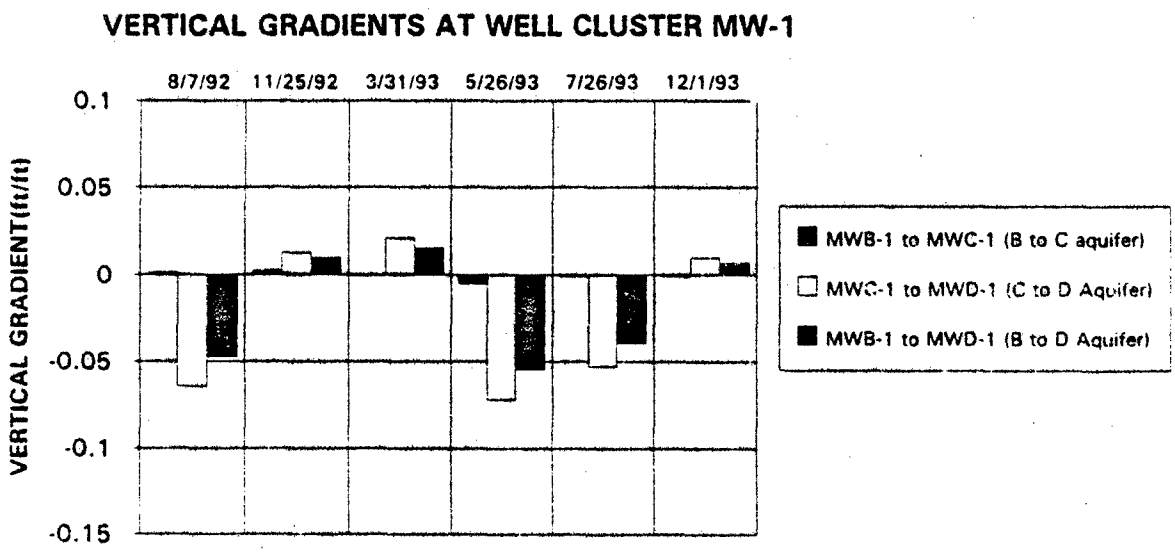
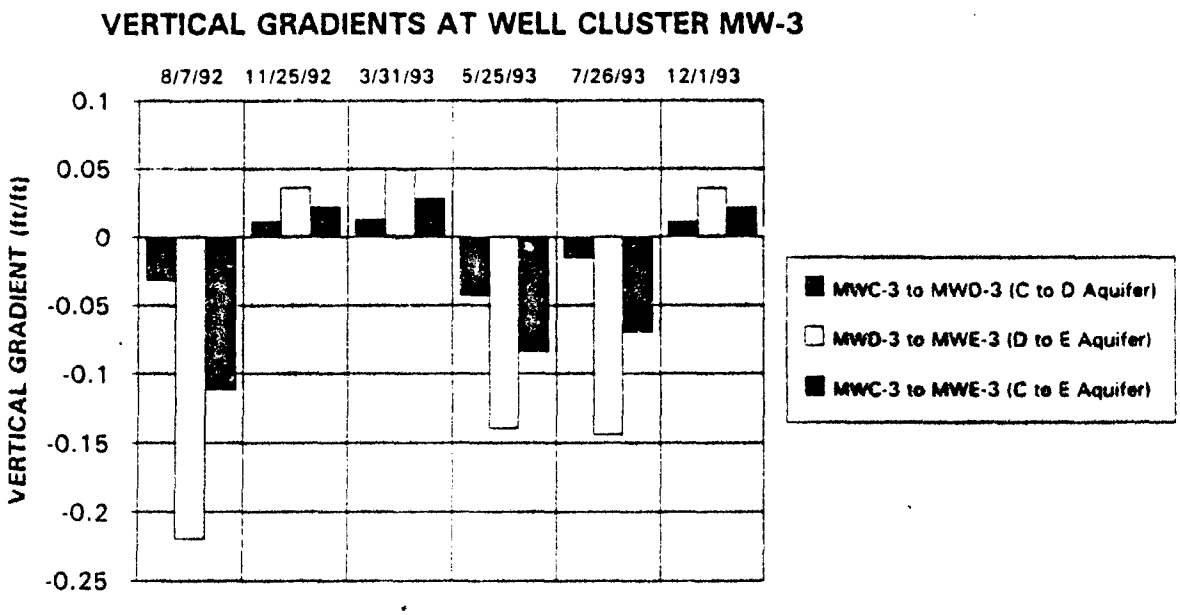
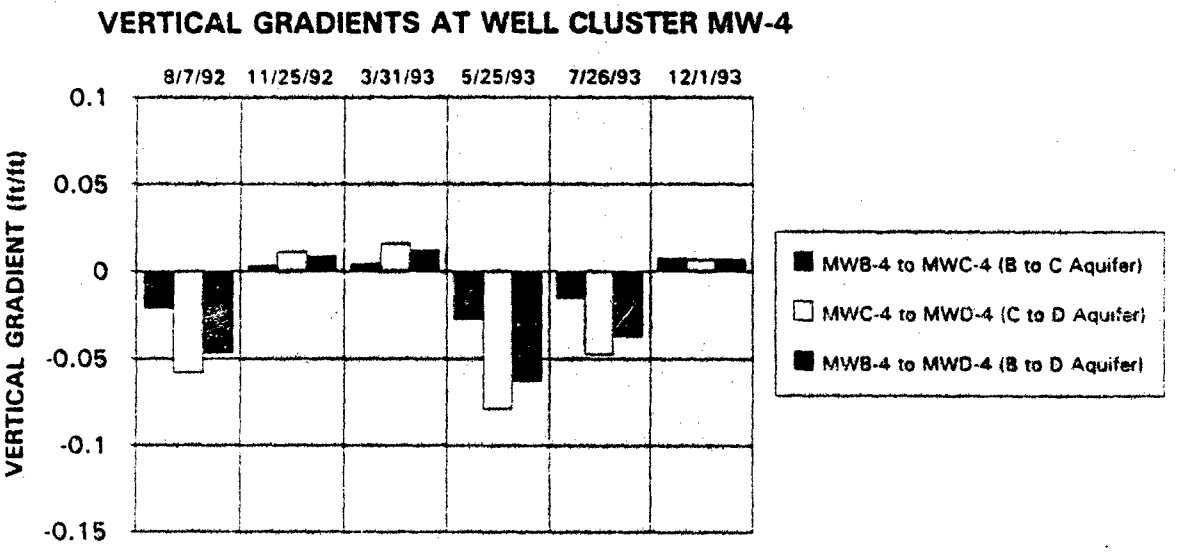
The following compounds were not detected
t-1,2-DCE, VCL, BEN, 1,1-DCE, 1,1-DCA

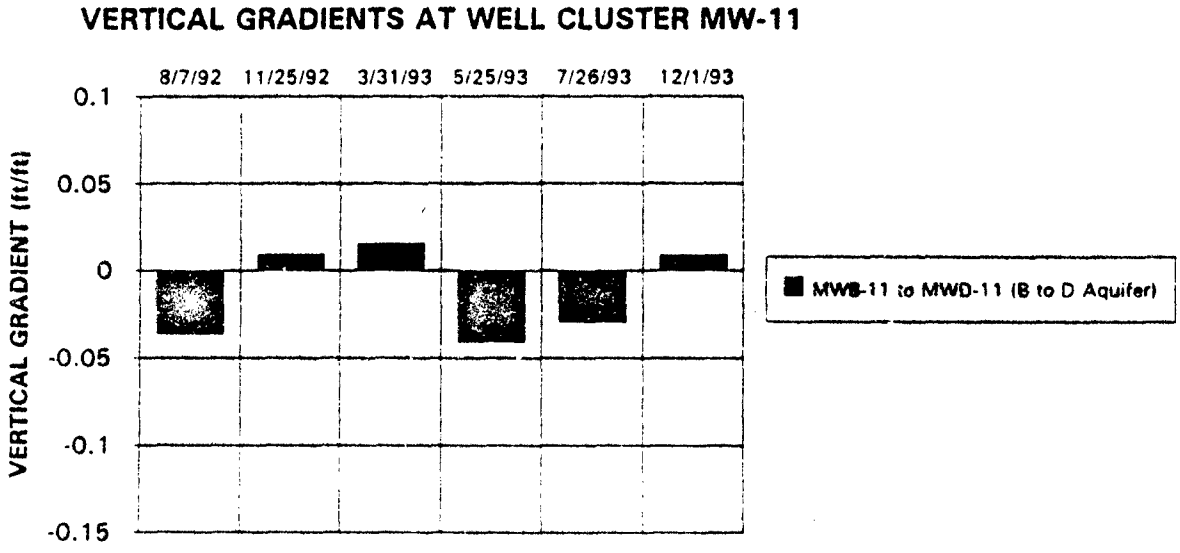


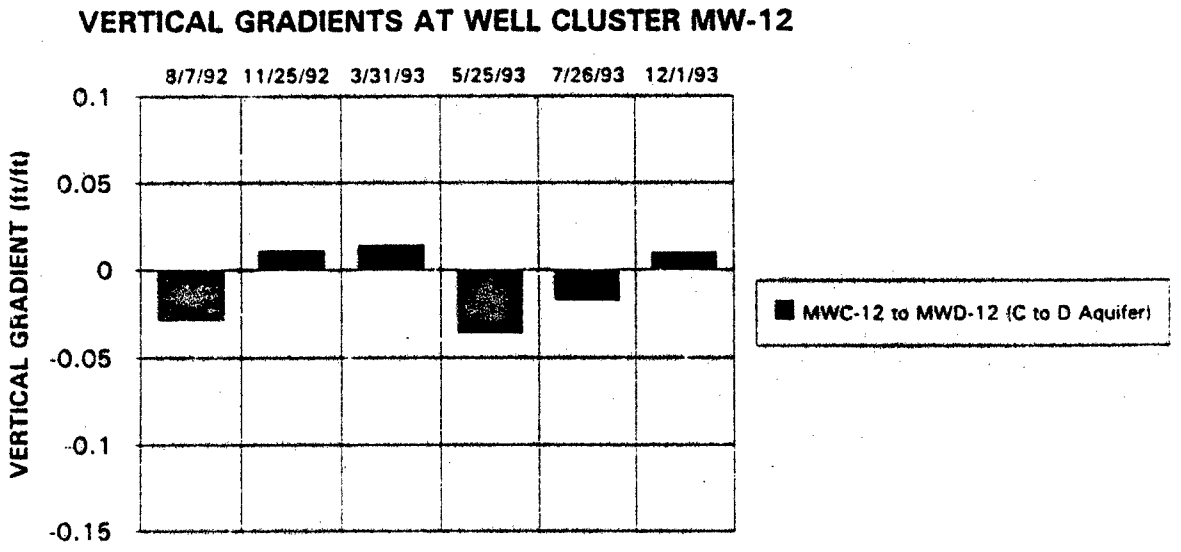
Attachment RC-2

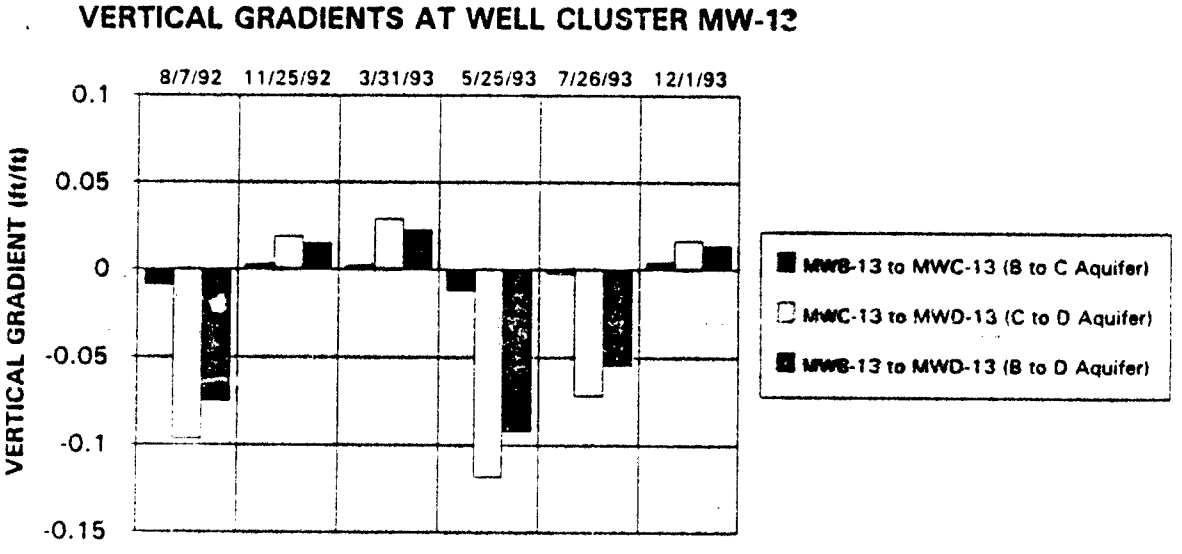

VERTICAL GRADIENTS AT WELL CLUSTER MW-1
8/7/92
11/25/92
3/31/93
5/26/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
VERTICAL GRADIENT(ft/ft)
MWB-1 to MWC-1 (B to C aquifer)
MWC-1 to MWD-1 (C to D Aquifer)
MWB-1 to MWD-1 (B to D Aquifer)

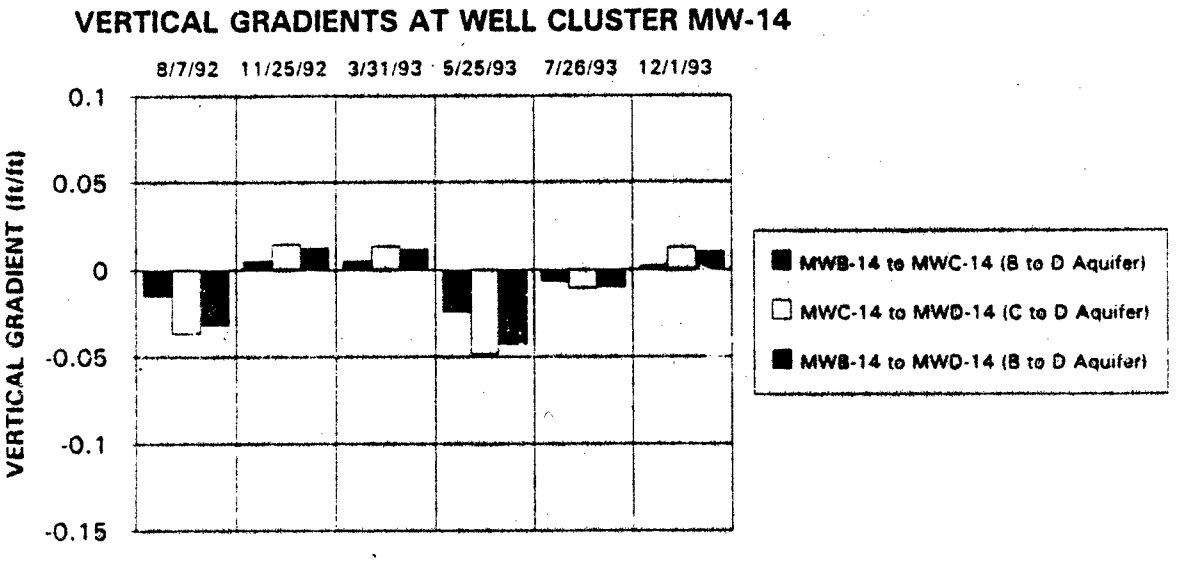

VERTICAL GRADIENTS AT WELL CLUSTER MW-3
8/7/92
11/25/92
3/31/93
5/25/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
VERTICAL GRADIENT (ft/ft)
MWC-3 to MWD-3 (C to D Aquifer)
MWD-3 to MWE-3 (D to E Aquifer)
MWC-3 to MWE-3 (C to E Aquifer)


VERTICAL GRADIENTS AT WELL CLUSTER MW-4
8/7/92
11/25/92
3/31/93
5/25/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
VERTICAL GRADIENT (ft/ft)
MWB-4 to MWC-4 (B to C Aquifer)
MWC-4 to MWD-4 (C to D Aquifer)
MWB-4 to MWD-4 (B to D Aquifer)

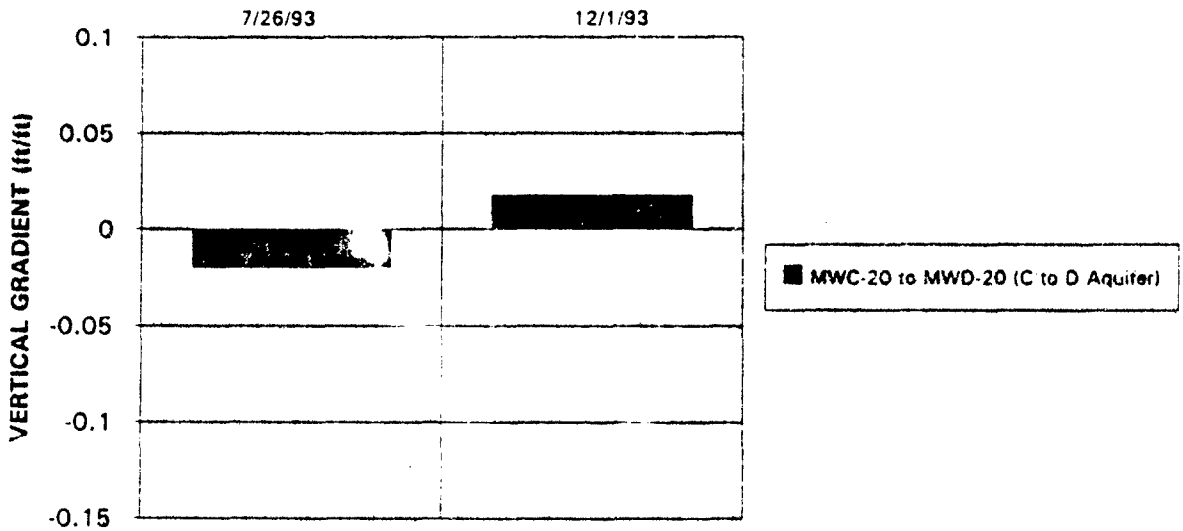

VERTICAL GRADIENTS AT WELL CLUSTER MW-11
8/7/92
11/25/92
3/31/93
5/25/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
VERTICAL GRADIENT (ft/ft)
MW8-11 to MWD-11 (B to D Aquifer)


VERTICAL GRADIENTS AT WELL CLUSTER MW-12
8/7/92
11/25/92
3/31/93
5/25/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
VERTICAL GRADIENT (ft/ft)
MWC-12 to MWD-12 (C to D Aquifer)

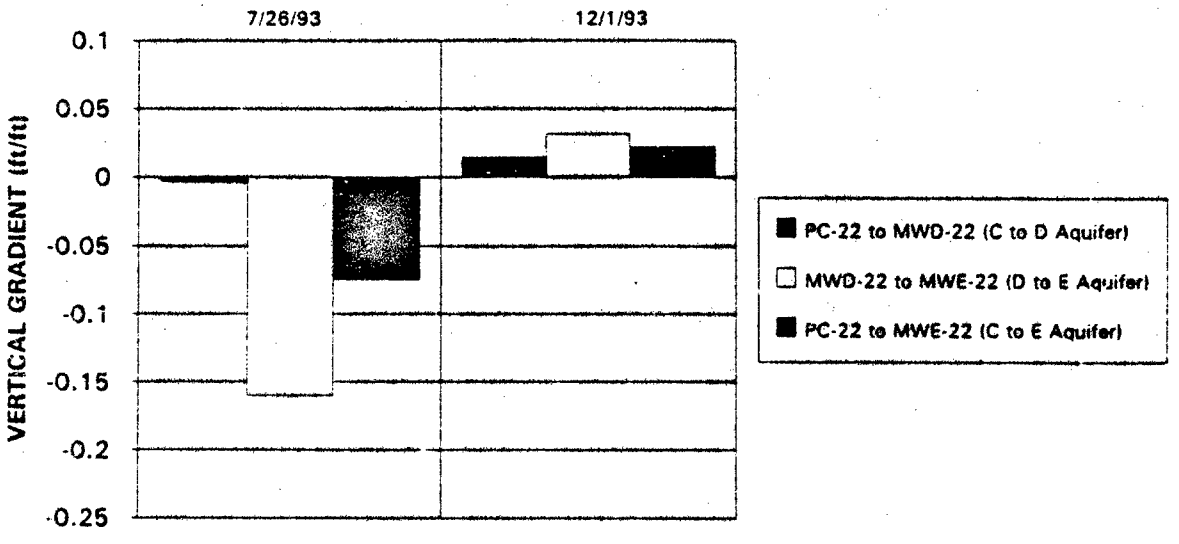

VERTICAL GRADIENTS AT WELL CLUSTER MW-13
8/7/92
11/25/92
3/31/93
5/25/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
VERTICAL GRADIENT (ft/ft)
MWB-13 to MWC-13 (B to C Aquifer)
MWC-13 to MWD-13 (C to D Aquifer)
MWB-13 to MWD-13 (B to D Aquifer)


VERTICAL GRADIENTS AT WELL CLUSTER MW-14
8/7/92
11/25/92
3/31/93
5/25/93
7/26/93
12/1/93
0.1
0.05
0
-0.05
-0.1
-0.15
VERTICAL GRADIENT (ft/ft)
MWB-14 to MWC-14 (B to D Aquifer)
MWC-14 to MWD-14 (C to D Aquifer)
MWB-14 to MWD-14 (B to D Aquifer)

VERTICAL GRADIENTS AT WELL CLUSTER MW-20



VERTICAL GRADIENTS AT WELL CLUSTER MW-22



Attachment RC-3

STATE OF CALIFORNIA—ENVIRONMENTAL PROTECTION AGENCY PETE WILSON, Gov

DEPARTMENT OF TOXIC SUBSTANCES CONTROL
REGION 1
10151 CROYDON WAY, SUITE 3
SACRAMENTO, CA 95827-2106
(916) 255-3545

February 14, 1994

Ms. Doris Bajka
SM-ALC/EMR
5050 Dudley Boulevard, Suite 3
McClellan Air Force Base, California 95652-1389

APPROVAL OF THE DRAFT FINAL REMEDIAL INVESTIGATION/FEASIBILITY STUDY (RI/FS) REPORT FOR THE DAVIS GLOBAL COMMUNICATIONS SITE

Dear Ms. Bajka:

The Department of Toxic Substances Control and the California Regional Water Quality Control Board, Central Valley Region (Agencies) have reviewed the response to the Agencies' comments on the Draft RI/FS report, which were contained in the Draft Final RI/FS Report, dated January 7, 1994.

The responses adequately address the Agencies' comments and we approve the RI/FS report.

If you have any questions or comments regarding this matter, please contact Mr. Mark Malinowski at (916) 255-3717.

Sincerely,

Eric Hong, P.E.
Chief
Federal Facilities Unit
Office of Military Facilities

cc: Mr. Alex MacDonald
Regional Water Quality Control Board
Central Valley Region
3443 Routier Road, Suite A
Sacramento, California 95827-3098

Mr. Tom To
Director of Environmental Health
Yolo County Environmental Health Services
10 Cottonwood Street
Woodland, California 95695

Post-it™ brand fax transmittal memo 7671 | # of pages ▸ 1

To Doris Bajka	From M. Malinowski
Co. EMR	Co. DTSC
Dept.	Phone # 255-3717
Fax # 8543-0827	Fax # 255-3697

STATE OF CALIFORNIA - Environmental Protection Agency PETE WILSON, Governor

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION
3443 Routier Road, Suite A
Sacramento, CA 95827-3098
PHONE: (916) 255-3000
FAX: (916) 255-3016

3 February 1994

Mr. Mark Malinowski
Department of Toxic Substances Control
Region 1
10151 Croydon Way, Suite 3
Sacramento, CA 95827-2106

DRAFT FINAL REMEDIAL INVESTIGATION/FEASIBILITY STUDY REPORT, DAVIS GLOBAL COMMUNICATIONS SITE, MC CLELLAN AIR FORCE BASE

Regional Board staff have reviewed the subject report and have determined that our comments on the draft version of the report have been adequately addressed. We presented some additional minor comments at the Interim Remedial Investigation scoping meeting held on 1 February 1994. We are not concerned whether or not the comments are incorporated into the final version of the report as incorporation would not change the findings of the report, only make it somewhat more accurate. Thus, we have no more formal comments.

If you have any questions regarding this matter, please call me at (916) 255-3025.

ALEXANDER MACDONALD
Project Engineer

AMM

cc: Ms. Doris Bajka, Environmental Management, McClellan Air Force Base

SUBJECT: Draft Remedial Investigation/
Feasibility Study
Davis Global Communications Site
McClellan Air Force Base

PROJECT: SWE28722.55.19

DATE: January 10, 1994

Comments on the November 1, 1993, Draft Remedial Investigation/Feasibility Study Report for the Davis Global Communications Site were received from the following reviewers:

- Martin Keck, Environmental Counsel, SM-ALC/JAV
- Alexander MacDonald, Project Engineer, California Regional Water Quality Control Board
- Mark Malinowski, Associate Engineering Geologist, Site Mitigation Branch, Department of Toxic Substances Control
- Mark D. Vest, R.G., Associate Engineering Geologist, Base Closure Branch, Department of Toxic Substances Control

These reviewers' comments are presented in this section along with responses to the comments. Where necessary, modifications to the report have been made. Copies of the original comments received follow this Response to Comments section.

Martin Keck

2. **My principal concern with this exhaustive and well-written report is that it fails to reflect the unique position of the Air Force as the lead agency in our cleanup. I believe the authors have used a plug-in approach for many of these chapters, utilizing discussions from other, previously written products. This is not inappropriate, and I have no objection to it. It is apparent, however, that EPA was usually the lead agency for these earlier efforts, and the discussions when applied to our cleanup need to be fine-tuned. I will illustrate several examples.**

a. **Volume I, Executive Summary, p viii, 2d full paragraph: The remedial action will be selected by McClellan, and must meet approval by EPA, DTSC, and RWQCB.**

Response:

The text has been revised as follows:

"The remedial action will be selected by McClellan AFB and must meet approval by Cal/EPA."

b. **Volume II, Appendix G, p G-1, 1st full paragraph under "Description of ARARS": Final determination of ARARS is made by AF, not EPA.**

Response:

This paragraph has been changed to reflect that the final determination of ARARs will be made by the California Environmental Protection Agency (Cal/EPA). This change can be found on page G-1.

c. **In the very next paragraph, it states that "EPA may use..." It should read "the Air Force may use..."**

Response:

This sentence has been changed to reflect that Cal/EPA may use guidance advisories as matters "to be considered." This change is presented on page G-1.

d. **At p G-2, 2d paragraph: The second sentence states that ARARS must be timely identified to EPA. It should read that they must be identified to the Air Force.**

Response:

The phrase "to EPA" has been deleted from this sentence as shown on page G-2.

My review may not have found all the instances where the authors have unthinkingly operated from the assumption that EPA is the lead agency. We should be careful to correct any such instances.

3. **Volume I, p 7-3, Table 7-1: For the Containment methyl isobutyl ketone, the 3d column fails to list a potential remedial approach, which I assume should be ground water extraction.**

Response:

Groundwater extraction was added to the third column of Table 7-1.

4. **Volume II, Appendix G, p G-11, 2d full paragraph: This discussion refers to a permit issued to our ground water treatment plant. It should note that the permit was not renewed due to our CERCLA permit exemption for on-site activities. Thus, while the permit itself is not an ARAR, the effluent levels referred to in the inactive permit may reflect substantive requirements with which the Air Force must comply.**

Response:

The paragraph has been changed to reflect that the NPDES permit limits are examples of the limits that may be placed on a similar treatment plant discharge at the Davis Site. The changes can be found on page G-11.

5. **Appendix G, p G-16, Table G-4, Item 16: The cite to 20 CFR 1910.120 should instead be 29 CFR 1910.120.**

Response:

The citation has been changed to 29 CFR.

6. **Appendix G, p G-25, top 2 paragraphs: I do not recognize the citations that begin with "R 18-8": I believe the correct citations are to 40 CFR.**

Response:

The citation has been changed to 40 CFR.

7. **Volume II, Appendix K, p K-11 (Table K-1), middle column, bottom tier: It states here that "all necessary permits should also be obtainable." No permits would be required for this on site bioventing, and this reference should be removed.**

Response:

The sentence has been changed to read "In addition, the substantive portions of any permitting requirements can be met." This change can be found in Table K-1.

Alex MacDonald
California Regional Water Quality Control Board

Volume I

1. **Target Area for C Aquifer. Figure 4-1a shows the target area for ground water remediation based on data collected from monitor wells prior to March 1993. The additional ground water sampling and analysis on samples collected since that time shows the target zone should be expanded farther to the south. Monitor well PCC-21 which is depicted as the outer boundary of the target area was found to have 132 μg/l TCE. Using this data, the target zone for the C aquifer would be expanded significantly and the calculated mass estimate will be much greater. The mass calculations and the target zones should be reevaluated.**

   The new ground water data was used to determine if the proposed extraction rates and zones of capture would be sufficient to capture the extent of contamination. To do this, the new target zone would have to been developed. This new zone should be presented in the draft final version of the report.

Response:

New target volumes were developed on the basis of contaminant data through July 1993. The mass estimates for each zone were revised accordingly.

2. **The Target Area for the D Aquifer. The comment for the C Aquifer Target Area applies in general to that depicted for the D Aquifer on Figure 4-1b. The ground water concentration isocontours should be reconfigured after adding the data from the ground sample collected from the D zone during the drilling of MWE-21. This data will yield a greater volume and mass of contaminants than that calculated for the report.**

Response:

See response to Comment 1.

3. **Vadose Zone Target Area. Though staff agrees generally with the defined target zone, we believe that the data presented in the cross-sections depicts the possibility of a greater target volume at depth than that shown on Figure 4-2a. The shallow soil gas sampling is likely not sufficient to define the extent of soil gas contamination at depth. As part of the last phase of Remedial Investigation field work, some borings and associated soil gas sampling should be included. These borings could be converted to soil gas monitor/extraction wells as necessary. If they are converted to monitor wells they will be useful in determining the zone of capture of the soil gas extraction system. This point was discussed in your office during the last several weeks.**

Response:

Table 7-2 was revised to include deep soil gas sampling as an additional investigation.

4. **Section 4.2.2, Mass of Contamination. The mass of contamination in the ground water should be calculated using all the available data. See Comments 1 and 2, above.**

Response:

See response to Comment 1.

5. **Figure 4-6a. The inert figure should also show the lines for TCE and t-1,2-DCE.**

Response:

The figures have been revised to show TCE and 1,2-DCE.

6. **Figure 4-16. Similar to the other cross-sections, the vadose zone contamination should be depicted if sufficient data is available completed monitor wells? The results from these wells, sampled in July 1993, should be added to the report.**

Response:

The figures have been revised to show July 1993 contamination.

7. **Page 6-6, first paragraph. It is stated that there should be no need to install additional wells for monitoring purposes. As stated above, staff is not of the opinion that the extent of deeper contamination in the soil gas has been determined. In addition, there may need to be additional monitor wells to determine the effective radius of capture of the extraction system.**

Response:

Additional monitoring points may need to be installed for the zone of seasonal water table fluctuation, located 40 to 70 feet bgs. Costs for installing additional wells are not included in the estimates presented in Section 6.3.7.

8. **Figure 6-5. The extraction wells for the D Aquifer should be moved as discussed during our recent teleconference.**

Response:

The figure has been changed to show actual locations of the new D aquifer wells.

9. **Table 7-1. It is listed in this table that the semivolatile organic contaminants will be potentially remediated at the site by bioventing. Has this method been shown effective on the semivolatile contaminants?**

Response:

Soil bioventing may or may not be suitable for any of the specified semivolatile compounds. Numerous site-specific factors (such as presence of sufficient populations of degraders; correct soil physical conditions such as water content, permeability, soil particle sizes; presence of metabolic inhibitors such as high concentrations of heavy metals; concentration of target contaminants; presence of alternative substrates) should be investigated before commencing soil bioventing.

However, all of the specified semivolatile compounds have been shown to be degradable under aerobic conditions. This implies that soil bioventing has the potential to be effective for these compounds.

10. **Chapter 7, Conclusions. Conclusions should be revised based on the above comments.**

Response:

The conclusions have been revised to incorporate the new numbers for contaminant mass.

Volume II

1. **Appendix F. Data from the newly installed ground water monitor wells should be included in this appendix to show ground water contaminant contours and development of mass estimates. The latest data may alter the presented values to some extent.**

Response:

Data from the new wells were incorporated into the mass estimates, and the new values are presented in Appendix F.

2. **Appendix F, figure F(a)-1. With the presented data for concentrations in the C Aquifer, the C Aquifer target area appears to extend to far to the northwest. The same thing can be said for the D Aquifer target volume as delineated in Figure F(a)-2.**

Response:

New target areas (volumes) are presented in the figures.

3. **Appendix F, page F-23. It is stated that in the conclusions that the extent of contamination in the vadose zone is based on the results of the shallow soil gas survey. Those results may not be indicative of the contamination at depth. The target area needs further definition with deeper soil gas sampling.**

Response:

See response to Comment 3, Volume I.

4. **Appendix F. Pages F-22 through F-24 are repeated as F-26 through F-28.**

Response:

The text has been revised to reflect the correct order.

5. **Appendix F, page F-29. It is stated that the organic fraction value used in the analyses was based on sample results and is considered a fair representation of the site values. Only one sample was analyzed for organic carbon content. It may or may not be representative of the site, but is better than using a book value.**

Response:

The text has been revised to read as follows:

> "The f_{oc} value was based on the average of four samples collected during the installation of soil vapor monitoring wells."

6. **Appendix G, page G-10, sixth paragraph. The Basin Plan for the Central Valley Region establishes the beneficial uses of specific water bodies within our region. The *Inland Surface Waters Plan* establishes water quality objectives for receiving waters to protect aquatic life and sources of drinking water from various pollutants.**

Response:

This paragraph has been changed to reflect that the Basin Plan establishes the beneficial uses of water bodies within the region, and the Inland Surface Waters

Plan establishes water quality objectives for receiving waters. These changes are presented on page G-10.

7. **Appendix G, paragraph 2. The permit for the discharge from the Ground Water Treatment Plant at McClellan AFB is not an ARAR for the Davis Transmitter Site. It is, however, an example of the limitations that might be placed on a similar discharge from the a Davis site ground water extraction and treatment discharge. The regulations used to develop the McClellan AFB permit would be the same as those that would be applied to the Davis site.**

Response:

This paragraph has been changed to reflect that the NPDES permit limits are examples of the limits that may be placed on a similar treatment plant discharge at the Davis Site. The changes are presented on page G-11.

8. **Table G-6. This table of ARARs should include the California Water Code for discharge of wastewater effluent from the treatment plant. Cleanup values for the vadose zone and ground water must comply with SWRCB Resolution 68-16 as an ARAR, with Resolution 92-49 as a TBC. Chapter 15 does not apply to the discharge from the treatment plant to a surface water.**

Response:

The California Water Code citation remains unchanged; however, the sentence preceding it has been changed to specify that the code applies to the discharge of wastewater effluent from a treatment plant. SWRCB Resolution 68-16 and Title 23, Division 3, Chapter 15 have been added as ARARs to the "Vadose Zone and Groundwater Treatment" row. Resolution 92-49 has also been added to this row as a TBC. Title 23, Division 3, Chapter 15 has been deleted from the "Discharge of Wastewater Effluent from Treatment System" row. These changes are presented in Table G-6, page G-24.

9. **Appendix G, page G-30, first paragraph. Cleanup of soils and ground water to background concentrations, unless proven technically and economically infeasible, is required in Resolution 68-16 and Title 23, Division 3, Chapter 15.**

Response:

This paragraph has been changed to reflect that Title 23, Division 3, Chapter 15 also contains the requirement to clean up soils and groundwater to background concentrations unless proven to be technically and economically infeasible.

10. **Appendix J, Figure J-19. The first decision diamond on the right side of the flow diagram does not have a "Yes" path associated with it. Two other decision diamonds have two arrows leading from them but only the "no" path is delineated.**

The first box on the right side states that the extraction wells should be each sample and composited. Why not just sample the influent to the treatment system to determine mass loading to the treatment system. A certain frequency of sampling the individual extraction wells for separate analysis should also be postulated.

Response:

The figure and associated text have been revised to respond to the comment.

11. **Appendix M, Costs for treatment options. The section was improved over the working copy. Some minor changes are still needed as follows:**

    a. **Labor costs for GAC are twice as high as those for the other treatment options even with the same number of hours.**

    b. **Why is the cost of additional labor more for TV1 GAC than for TV2 even though the same number of hours are required?**

    c. **Why are there twice as many samples for TV2 as TV1?**

    d. **Table M(a)-7. The O&M costs listed for GAC TV2 appear to be in error.**

Response:

a. The labor cost for the GAC was miscalculated and corrected. A similar error was found for UV Oxidation. The changes are presented in Attachment M(a)-2 and Tables M(a)-5 and M(a)-6.

b. The additional labor for TV1 and TV2 should have been the same and was corrected. The changes are presented in Attachment M(a)-2 and in Tables M(a)-5 and M(a)-6.

c. The number of samples increased for TV2 because an additional unit was needed to treat the increase in the amount of flow. This is discussed on page M-8 under Operation and Maintenance Costs, the third bulleted item – Analytical.

d. The O&M cost of GAC TV2 in Table M(a)-7 was an error and has been corrected.

Mark Malinowski
Department of Toxic Substances Control

Volume I of III

General Comments

1. **The report is well written and organized. The groundwater mass and volumes should be updated to include the most recent groundwater sampling data.**

Response:

The groundwater mass and volumes were changed to include the July 1993 sampling results. Electronic groundwater sampling data from the April and July 1993 sampling events are pending. It is expected that these data will be incorporated into the database for the Davis Site and included in Appendix U for the Final copy of the report. However, groundwater quality data through July 1993 were incorporated into the site cross sections, target volumes, and hydrogeologic interpretation.

2. **Given the screen interval, monitoring well MWD-2 should be re-labeled as MWC-2.**

Response:

It will be noted that MWD-2 is actually a C aquifer well; however, the actual well name will remain the same.

3. **When metric weights (kg) are provided, also include the U.S. customary weights (pounds or ounces).**

Response:

The equivalent weights in pounds have been added to metric weights in kilograms.

4. **The monitor well Concentration versus Time plots should use a log scale along the concentration axis. The log scale provides better resolution at low concentrations.**

Response:

The monitoring well time versus concentration plots will be changed so the concentration axis will be a log scale. Plots of concentration versus time for all wells will be supplied after issuance of the Draft Final report and before the issuance of the Final report.

Specific Comments

1. **Page iii, paragraph 4. Specify the vadose zone "objectives."**

Response:

The text was revised to read as follows:

> "Objectives for the RI/FS were divided into vadose zone and groundwater actions. The vadose zone objectives included determining the extent of soil gas contamination, identifying areas of VOC contamination, identifying areas where soil vapor monitoring wells should be installed, and providing contaminant data that could be used in human health or ecological risk assessment activities."

2. **Page viii, Conclusions. The Executive Summary Conclusions should summarize the short narratives presented in Chapter 7 (e.g., vadose zone contamination will continue to contaminate groundwater if action is not taken. VOC contamination continues to spread downward and outward. SVE would reduce VOC mass in the vadose zone adequately and prevent continued contamination of the groundwater. Groundwater containment systems would inhibit off-site migration of groundwater.)**

Response:

The text was revised to read as follow:

A full list of conclusions generated during the site evaluation are presented in Chapter 7, along with recommendations for additional work. The list of COCs and potential remedial actions for each COC is tabulated in Chapter 7.

The following is a synopsis of the conclusions:

- If left unchecked, vadose zone contamination will continue to degrade groundwater quality for several hundred years.
- Steep downward vertical gradients and increased horizontal gradients that exist beneath the site during the late spring and summer promote contaminant movement from shallow, more contaminated zones to deeper, less contaminated, more transmissive aquifers. This results in larger target volumes for groundwater remediation, especially in the C, D, and E zones, which translates into higher costs for the eventual remedial action.
- Implementation of soil vapor extraction within the vadose zone would reduce or remove the threat of contaminant loading to the groundwater.

- Groundwater extraction and treatment would inhibit offsite movement of groundwater contamination and serve to remediate subsurface contamination to levels accepted by the California Environmental Protection Agency.

3. **Page xvii, Glossary of Terms. Please define the following: anaerobic dehalogenation - halogen, biotransformation - chlorinated alaphatic.**

Response:

The comment is understood to request the following:

Define the term halogen used within the definition of anaerobic dehalogenation and define the terms chlorinated aliphatic within the definition of biotransformation.

The term halogen has been defined in the Glossary of Terms. The terms "chlorinated aliphatic" have been removed from the definition of biotransformation.

4. **Page 1-4, 1.2, paragraph 3. The reference to Figure 1-3 as a "timeline for remedial investigative activities" is not accurate. Figure 1-3 indicates only the contractors who worked on the site, not the work performed. Is Figure 1 3 missing verbiage on the right hand side that would indicate the contractor's efforts? (e.g., Kleinfelder - UST investigation., ITC - RI work - determine extent of groundwater contamination., Radian - quarterly groundwater sampling., etc.) Radian did perform some groundwater sampling in 1988.**

Response:

The text and title of Figure 1-3 have been revised to read "Time-Line of RI Contractors at the Davis Site." The reader is directed to Figure 2-1 for a description of the work performed.

Our review of IRIPMS data and previous reports indicates that no groundwater sampling was performed by Radian in 1988. However, groundwater sampling was performed by ITC. This sampling is added to Figure 2-1. Results were included in Appendix U of the Working Copy.

5. **Page 1-4, Section 1.3.1. Include the main objective of the RI; gather enough information to be able to conduct a feasibility study, perform a remedial design and implement a clean-up action.**

Response:

The text was revised to read as follows:

> The principle objective of the RI is to compile sufficient data to perform a feasibility study, develop a remedial design, and implement a remedial action. This objective is divided into specific vadose zone and groundwater objectives.

6. **Page 4-3, Section 4.2. The contaminant mass estimates and target volumes should be revised based on the most recent sampling results.**

Response:

Contaminant mass estimates and target volumes were revised to include the July 1993 sampling results.

7. **Page 4-3; Section 4.2.1. Selection of Target areas should include estimated groundwater target volumes (total gallons) for each zone. Groundwater volumes for non-detect, MCL and 10^{-6} risk boundaries should be presented (Table format would probably be best.)**

Response:

Target areas have been changed to unit target volumes for each zone. The new groundwater target volumes for nondetect and MCL boundaries are presented below. Risk target volumes will not be presented based on consensus established at the June 30, 1993 meeting.

Target Areas and Unit Target Volumes

Zone	Nondetect Target Area (ft^2)/MCL Target Area	Target Area Thickness (ft)	Porosity	Nondetect Unit Target Volume (gal.)	MCL Unit Target Volume
Vadose Zone	131,200/NA	40	0.40	2,100,000 [a]	NA
A-B Aquitard	453,000/215,000	25	0.45	38,100,000	18,000,000
B Aquifer	453,000/215,000	30	0.40	40,700,000	19,300,000
B-C Aquitard	649,350/150,000	20	0.45	43,700,000	10,000,000
C Aquifer	649,350/150,000	30	0.39	56,800,000	13,100,000
C-D Aquitard	969,000/425,000	20	0.45	65,200,000	28,600,000
D Aquifer	969,000/425,000	30	0.35	76,100,000	33,400,000
D-E Aquitard	950,000/0	20	0.45	63,900,000	0
E Aquifer	950,000/0	30	0.35	74,600,000	0

[a] Vadose zone unit target volume units of ft^3.

8. **Figure 4-6 (a-h). The Department recommends using a log scale for the concentration plots. Plots for all the monitoring wells at the site should be included as an appendix.**

Response:

See Response to General Comment 4.

9. **Figure 4-9. Intersection identified as G-G' should be H-H'. Contamination (red) should be depicted in PC-21, and extended from MWE-3 to MWE-21. Contamination should be illustrated throughout (vertically) the aquifer that is screened (see MWD-3). Contamination should be shown across the screened section of MWC-3. Explain the contamination indicated between MWC-3 and MWD-3.**

Response:

The recommendations were implemented and shown in the revised Figure 4-9. Contamination is shown throughout the screened interval in wells where contamination has been detected. Graphically, the red contamination is superimposed over coarse-grained layers. If the contamination is extended vertically throughout these units, the red color would obscure the unit. Therefore, we have left an outline of the coarse-grained unit around the contamination.

The contamination between MWC-3 and MWD-3 has been removed from the figure.

10. **Figure 4-10. Indicate the H-H' cross section intersection. EW-1C has been ND in 7/93 and 10/93. Contamination should not be shown in the C zone in this cross section.**

Response:

Figure 4-10 was revised as suggested.

11. **Figure 4-11. Contamination should be shown in MWE-22.**

Response:

Figure 4-11 was revised as suggested.

12. **Figure 4-12 . Provide the sampling results for MWC-1 and MWD-1.**

Response:

Figure 4-12 was revised as suggested.

13. **Figure 4-13. Sampling results from 7/93 for EW-3C and MWD-2 do not support the contamination depicted in the C aquifer. The contamination in the B zone should extend east, past MWB-13.**

Response:

Figure 4-13 was revised as suggested.

14. **Figure 4-14. Provide the sampling results for MWC-4.**

Response:

Figure 4-14 was revised as suggested.

15. **Figure 4-16. Groundwater contamination should be depicted southwest past EW-3C (B zone), and MWD-10 (D zone), and northeast past MW-6 (B zone). As previously stated, the C zone sampling data do not support the contamination depicted. It appears that contamination is migrating downward, from the B to the C, near the MW (X)-3 cluster. Include the 7/93 data for MWE-3.**

Response:

Figure 4-16 was revised as suggested. Note the projection lines.

16. **Figure 4-17. Contamination should be depicted in the E zone.**

Response:

Figure 4-17 has been revised to show contamination in the E zone.

17. **Page 5-5, Section 5.3. The "clean-up levels" for groundwater are actually "targets levels." This section should indicate that the FS evaluates the cost to clean-up groundwater to background, MCLs and 10^{-6} risk.**

Response:

See response to Specific Comment 7. The feasibility study evaluates the cost to clean up to background levels.

18. **Page 6-6, paragraph 1. Additional soil gas monitoring/extraction wells should be considered to evaluate the subsurface zone that is saturated in the winter, but dewatered in the summer.**

Response:

Language has been added that recognizes the possible need for additional monitoring points for the "zone of seasonal water table fluctuation."

19. **Page 6-6, Section 6.2.3.2. Does the site have a natural gas line? If not, have the additional costs to install a gas line been incorporated into the CatOx cost evaluation?**

Response:

The Davis Site does not currently have a natural gas line. We are not aware of any plans to install a gas line in the near future. If a gas line is not installed, a portable propane tank will be required to supply the fuel. Using a portable propane tank would increase the annual O&M cost of the CatOx system by approximately $7,500. This would increase the O&M cost for offgas treatment presented in Table 6-9 from $28,000 to $35,500.

20. **Page 6-8, Section 6.2.4. The FS should use the target volumes generated in Chapter 4, and evaluate the cost to clean-up groundwater to background, MCLs and 10^{-6} risk. Use of the term Target Volume for groundwater is inaccurate since no volumes are presented.**

Response:

The feasibility study used the new target volumes presented in Chapter 4. The feasibility study also presented the cost to clean up to background levels only based on consensus established during the June 30, 1993 meeting.

21. **Page 6-9 Figure 6-5. The figure should be revised to indicate the location of the extraction wells based on the November, 1993 teleconference between CH2M HILL, McAFB, the RWQCB and DTSC.**

Response:

The new locations of the D aquifer extraction wells have been incorporated into Figure 6-5.

22. **Page 6-11, Section 6.2.4.3. Include a paragraph describing the need to drill exploratory holes to ensure reinjection is viable (technically, i.e., aquifer capability, regulatory i.e., groundwater quality between injected water and aquifer water.)**

Response:

The following text has been added:

> As a first step to drilling reinjection wells, exploratory test holes should be drilled to define the stratigraphy and presence of coarse-grained units. An attempt should be made to collect aquifer soil samples. The samples should be analyzed to determine if the soil matrix is compatible with the injection water in terms of geochemistry and aquifer clogging. Geophysical logging of the test hole and logging of the test hole cuttings will give an indication of the hydraulic properties of the formation.

23. **Page 6-35, Table 6-12. The Target Areas should be volumes. Estimates for groundwater should be provided in some measure appropriate for water (e.g. gallons or acre feet.) The Vadose Zone Target Area (Volume) should be in cubic feet.**

Response:

Reference to groundwater "target areas" has been deleted from the document. The term "unit target volume" is now used to provide a measure of the volume of water within the specified groundwater target volume, or the volume of air within a vadose zone target volume. Unit target volumes in Table 6-12 are referred to in units of gallons for groundwater, and units of cubic feet for the vadose zone.

24. **Mass of Contamination is underestimated due to a lack of understanding/measuring contaminant adsorption to soils.**

Response:

It is acknowledged that the contaminant mass estimate may be within an order-of-magnitude of the actual contaminant mass.

25. **Page 6-39, Table 6-14. Include the costs for capturing contamination that exceeds 10^{-6} risk.**

Response:

The cost for capturing contamination that exceeds 10^{-6} risk is not included as consensus established at the June 30, 1993 meeting.

26. **Page 7-2, Section 7.3, paragraph . Include the State of California's Non-Degradation requirements in this section as a reason for taking action.**

Response:

Remedial action is warranted at this site to satisfy the Regional Water Quality Control Board (RWQCB) nondegradation requirement for groundwater and vadose zone contamination. Groundwater and vadose zone contamination needs to be restored to background conditions.

27. **Page 7-2, Section 7.5. Include additional "deep" soil gas sampling.**

Response:

Table 7-2 has been changed to add deep soil gas sampling as an additional investigation.

Volume II of III

1. **Page B-2. Provide a map showing the five SVMWs and nine piezometers locations. Specify the dates of the tests and the most recent rainfall event and amount of precipitation.**

Response:

The five soil vapor monitoring wells and nine piezometers are shown on Figure B-4. The dates of the tests and the most recent rainfall event are shown in Table B-1.

2. **Figure B-2. The response of the SVMWs and piezometers are suspiciously matched to the barometric pressure. Can you provide any insight to the correlation? The data for the air permeability tests at CH-1 and 5 do not appear to correlate as closely.**

Response:

On the basis of air permeability testing results, surface barometric pressure fluctuation would be measureable in the subsurface within 1 hour after change on the surface. Therefore, it is expected that any barometric fluctuation would be measured in the subsurface during testing with a lag period of at least 1 hour.

3. **Page B-17, paragraph 1. Is it possible that the biological activity (no measured oxygen) caused the positive pressure observed in the CH-5 well?**

Response:

It is unlikely that biological activity in the vicinity of CH-5 could generate the pressures needed to record positive pressures in the piezometers at depth. It is much more likely that infiltrating rainfall would create positive pressures in the subsurface.

4. **Page B-17. Recommendations are not supplied. Are additional SVE wells needed? Will additional testing be needed prior to installing SVE wells? Will the existing wells be adequate for performing SVE or should larger diameter wells be installed? Should air permeability tests be conducted in the summer and winter to evaluate the impact of soil moisture and level of groundwater? Would soil moisture profiles be helpful in evaluating the air permeability results? Will larger diameter SVE wells have any significant effect on the radius of influence?**

Response:

The text has been revised as follows:

Recommendations

Air permeability results were used as input data for modeling of airflow in the vadose zone at the Davis Site. A discussion of the air modeling and SVE requirements are presented in Appendix I. Refer to Appendix I for details on the design and operation of the proposed SVE system. Using the results generated from the air permeability testing, the following recommendations have been formulated:

- The five existing SVMW can be used as SVE wells during operation of an SVE system. Flow rates up to 100 scfm can be applied to the existing 2-inch wells.
- At this time, no additional SVE wells are needed for an SVE system.
- If additional SVE wells are needed for soil vapor capture, the wells should be no smaller than 4 inches in diameter.
- Additional air permeability testing during the dry season may result in different air permeability values because of differing antecedent moisture conditions.

5. **Page D-4, paragraph 1. Field Exploration Have owls been observed in the soil piles? The data for samples from the northern and eastern soil piles could not be found in Table U-1.**

Response:

The text has been revised as follows:

"These piles do not appear to have been disturbed since their placement; however, rodent burrows have been observed in the piles."

6. **Page E-1. Provide concentration plots for all wells. Use the same scale (log) for all the wells. Provide tables, like J-1, for all the sampling episodes. Include groundwater elevations and detection limits.**

Response:

Time concentration plots will be provided for all of the wells using a log scale on the concentration axis. The plots will be provided in or before the Final copy of the report. Tables like J-1 will not be provided for all of the groundwater sampling episodes as consensus established during the January 4, 1994, teleconference with DTSC, McClellan AFB, and RWQCB.

7. **Page G-1, paragraph 2. The Davis site is a State Lead site. The EPA will not make the final determination of ARARs, as specified.**

Response:

This paragraph has been changed to reflect that the final determination of ARARs will be made by the California Environmental Protection Agency (Cal/EPA). This chan[illegible] is presented on page G-1. All other references to "EPA" in the appendi[illegible].ve been changed to "Cal/EPA."

8. **Page I-1. If SVE is viable for the interval between 40 feet bgs and the lowest (summer) seasonal water table, a section should be added to discuss the advantages and disadvantages.**

Response:

SVE is not an effective solution at this time for the "zone of seasonal water table fluctuation." A section has been added to the end of Appendix I that describes why it is not an effective solution. Dual-phase extraction may be the best method for removing contamination from this zone. Appendix O describes dual-phase extraction in detail.

9. **Figure J-19. AG pumping Diamond - Define a time period (i.e. 2-3 weeks). Adjust Q Box - It may not be necessary to adjust "all" well(s). The logic for the two "Adjust Target Area" Diamonds is not clear. What is the difference between the McAFB adjust treatment box and the previous adjust treatment decision diamond and why does the McAFB adjust treatment box lead into another adjust treatment diamond? The "No" direction "clean-up criteria met?" diamond, should flow to all three decisions, "adjust target area?", "adjust treatment?" and "adjust monitoring frequency?". After the first quarter, how often will influent be sampled?**

Response:

The figure and text have been revised to respond to this comment.

10. **Page L-4. Gas Phase Carbon Adsorption. The Department recommends further discussion of the non-regenerative carbon DREs, as well as advantages and disadvantages. As described on page L-14, the Department would like McAFB to consider that the vinyl chloride (and probably methane) concentrations will drop rapidly after operation of an SVE system - reference OU-D SVE at McAFB. A small temporary CatOx unit may be adequate for initial operation. After vinyl chloride and methane concentrations drop, the carbon units would be effective in controlling off-gas emissions and cheaper to operate and maintain.**

Response:

Given that the concentration of vinyl chloride is relatively low to begin with, its concentration can be expected to decrease within a short time after implementation of the SVE system.

Methane was detected in only one well, but its concentration was so high compared to the rest of the contaminants (e.g., 30,000 times higher than that of vinyl chloride). Therefore, unlike vinyl chloride, it is difficult to assume that its presence will disappear in a short time after operation of the SVE system. This is why adsorption technologies were rated so low in the DRE category. However, as stated in the report, if methane emissions are acceptable to regulatory agencies, they could be given a much higher rank in the DRE category.

11. **Page L-5. Operation data at McAFB indicate that the Purus Padre system does, in fact, "capture" vinyl chloride.**

Response:

Yes. The operation data at McClellan AFB indicate that vinyl chloride is reasonably adsorbed by the Purus PADRE system. Up to approximately 71 percent DRE has been observed so far with respect to vinyl chloride.

12. **Page L-8. Screening Methodologies. Provide a more complete description of how the ranking was completed. In Table L-3 the Operational Costs: Carbon Adsorption = 4 (21,500); CatOx = 10 (28,000). Capital Costs: Carbon = 10 (19,800); CatOx = 3 (67,000). The Department would suggest that if the Carbon Operational rank is 4, yet it is less expensive than CatOx, how can CatOx receive a 10? If Carbon had a ranking of 10, carbon and CatOx would rank equally.**

Response:

Carbon and CatOx should have been ranked nearly equally. This change has been incorporated along with other changes. The way the ranks were given is that typically the option that ranked the most favorable against a criterion was given the highest rank. The rest of the options were then ranked relative to the highest ranking option. For example, the capital cost ($19,800) of the carbon system was assessed to be the lowest among all the other options. So, it was given the highest rank of 10. The capital cost of the CatOx system was assessed to be approximately three times that of the carbon system and therefore was given a rank of 3 in the same category.

Similarly, in the operating cost category, the carbon system should have been given a score of 10 since it was assessed to have the lowest operating cost. On the basis of the relative increase in operating costs for the other options, their ranks should have been proportionately decreased to the following: 3, 8, and, 3 for electron beam, CatOx, and PADRE technologies, respectively.

13. **Page L-10, Table L-2. CatOx. To ensure accurate capital cost, ensure that a natural gas line hook up is included in the cost. It is possible that the site does not have natural gas run to the site.**

Response:

Refer to the response to Specific Comment 19 for Volume I of III.

14. **Page L-11, Table L-3. The weighted rank scores for Carbon's Status Development, Feed Variability and Problem Compounds, should be corrected. The Weighted Total score is 735, unless the ranking for Operating costs are re-evaluated (see above comment.)**

Response:

The ranks given to the options for the "operating costs" category have been revised. However, the ranks for the other categories have not been changed. Changing the rank for carbon technology with respect to the problem compounds was considered, but not changed. This is because it was thought that the concentration of methane is extremely high to assume that it will decrease in a short time after implementing the SVE operations. Carbon is not

an effective method to control methane emissions; therefore, the rank assigned to carbon under this category was not changed.

15. **Page L-13, paragraph 3. Paragraph 3 states that given the low concentrations of contaminants, CatOx treatment is a "gross waste of energy..." and recommends another treatment technology. In Recommendations and Conclusions the only option for off-gas treatment (SVE and groundwater) is CatOx. The Department staff recognizes the need to acknowledge the apparent contradiction but suggests toning down the statement in paragraph 3.**

Response:

Although the operating costs for catalytic oxidation systems is one of the lowest among the technologies evaluated, its relative consumption of energy at the site for treating a gas stream with a low contaminant concentration and high flow rate is relatively high.

16. **Page M-2, paragraph 2. Groundwater Flows Clarify the first sentence. It is unclear what is meant by "...they will add insufficient difficulties to the treatment capabilities."**

Response:

The first sentence of paragraph 2 under Groundwater Flows has been revised as follows:

> "Since the contaminant concentrations in the D and E aquifers are minimal, they will not significantly increase the effort needed to remediate the B and C aquifers."

17. **Page O-1, paragraph 1. Edit. It is assumed that the "intermittent capillary zone" refers to the "fine grained soil within..." and not to the Davis Site.**

Response:

The "intermittant capillary zone" refers to the zone from approximately 40 to 70 feet bgs. The first paragraph in Appendix O has been revised as follows:

> "Dual-phase extraction has been proposed as a method of removing volatile contaminants that may be present in fine-grained soil within a zone of seasonal water table fluctuation at the Davis Global Communications Site (Davis Site). This zone of fine-grained soil occurs from a depth of approximately 40 feet to approximately 70 feet below ground surface (bgs) and consists predominately of silty lean to fat clays. As described in Chapter 3 of the Remedial Investigation/Feasibility Study (RI/FS) report, the fluctuation occurs as a result of regional pumping in

the summer, countered by seasonal recharge in the winter. In this appendix, this zone is referred to as the intermittent capillary zone."

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General Comments

1. **No "fatal flaws" were identified.**

2. **To support design, construction, and testing of a ground water containment and extraction system, certain maps and cross-sections should be amended to better illustrate that a sound understanding of the distribution of subsurface sediments and contaminants has been achieved.**

Response:

Major revisions have been made to the cross sections presented in Chapters 3 and 4.

3. **Tabular summaries of analytical data should be provided to support the illustrated distribution of contamination.**

Response:

Analytical data have been presented on time concentration plots and in Appendix U. Appendix U data will be provided to McClellan AFB in Excel format.

4. **As per the California Business and Professions Code, a sign-off should be provided by California registered geologist indicating responsibility for all geologic content of Report.**

Response:

The report will be stamped by a California registered geologist.

Executive Summary

5. **The Report states (p. iii) ". . . this report does not address hydrocarbon contamination as a portion of the remedial action."**

Recommendation: The Contractor should discuss any likely effects on operation of a ground water extraction and treatment system resulting from diesel constituents inadvertently recovered with volatile contaminants.

Response:

On the basis of historical water quality results, TPH-diesel constituents have not been detected at a regular frequency at the Davis Site. Benzene and toluene have been detected in samples from B aquifer monitoring wells. However, because the frequency and concentrations of TPH and BTEX constituents in groundwater are low, treatment system operation should not be effected.

6. **(Editorial) The Report states (p. iv) "Groundwater modeling results were performed to verify . . . ." It is not clear what is meant by, "results were performed".**

Response:

Sampling of groundwater from monitoring wells at the Davis Site is performed by Radian Corporation on a quarterly basis. This RI/FS Report includes data collected through July 1993. These data are used as the basis for the findings and recommendations presented in this report, including development of mass estimates, target areas and volumes, and groundwater modeling.

7. **Also on page iv, the Report mentions ground water analytical data that became available relatively late in the report preparation period.**

Recommendations:

a. **Ongoing collection and interpretation of data should be anticipated.**

b. **Summary tables, graphs, maps and cross sections should be developed with space reserved to add late breaking data.**

c. **The actual insertion of late breaking data into tables and graphics can be performed by the Contractor or by users of the documents.**

Response:

The executive summary text has been changed accordingly. Data through the July 1993 sampling have been incorporated into this report. Space will be reserved on the new time concentration plots for the plotting of additional data.

Chapter 1, Introduction

8. **On page 1-1, the Report discusses ground water contaminant data that became available relatively late during preparation of the Report. The Report states "These data were incorporated into site cross sections . . . and into the site groundwater modeling in Appendix J. Groundwater modeling was performed to verify that July 1993 data do not significantly impact the recommendations provided in this report."**

   Recommendations:

   a. **Refer to comment 7, above.**

   b. **The Report should briefly specify what additional ground water modeling was performed using the July data.**

Response:

   a. See response to Comment 7.

   b. The text was revised to read as follows:

      Groundwater modeling was performed to verify extraction well placement, extraction rates, and capture zones for the recommended remedial action. Groundwater modeling results are presented in Appendix J.

9. **On page 1-2, the Report further discusses separating remediation of the zone of diesel contamination from the VOC remediation.**

   Recommendation: Refer to comment 5, above. The Contractor should decide if diesel constituents are likely to effect extraction or treatment system operation.

Response:

   On the basis of historical water quality results, TPH-diesel constituents have not been detected at a regular frequency at the Davis Site. Benzene and toluene have been detected in samples from B aquifer monitoring wells. However, because the frequency and concentrations of TPH and BTEX constituents in groundwater are low, treatment system operation should not be effected.

10. **(editorial) Page 1-4 states "The Davis Site consists of the fenced, Main Compound Area (approximately 8 acres), communication antennas, and undeveloped grasslands (as shown in Figure 1-2)". Except for the fenced compound area, the figure does not show these features.**

    Recommendation: The text and/or figure should be amended to be consistent with one another.

Response:

The Davis Site is an annex of McClellan AFB in Sacramento, located approximately 4 miles south of the City of Davis (as shown in Figure 1-1).

11. **Page 1-8 provides three criterion that were used to develop contaminants of concern (COCs). Table 1-1, Contaminants of Concern, lists the COCs.**

Recommendation: The table should be amended to include an additional column specifying which criteria from page 1-8 led to inclusion of each compound in the list of COCs.

Response:

The comment column in the table has been modified so that the specific criteria that make a contaminant a COC are explicitly stated.

12. **A note at the base of Table 1-1 identifies a criterion to identify a "contaminant of potential concern".**

Recommendation: The Report should discuss the significance of the note and contaminants of potential concern.

Response:

The note at the end of the table is not needed and has been deleted.

Chapter 2, Field Investigation Activities

13. **Page 2-8, Table 2-2, Well Construction Data.**

Recommendations:

a. **An amended version of the table should be provided as part of Appendix S, Well Construction Data. In addition to the information provided on Table 2-2, the amended table should include well location, borehole diameter, total depth, drilling method, filter pack size gradation and interval, and surface completion type.**

b. **MWD-2 snould be listed with the C Aquifer wells. A foot note should be provided to explain the MWD label. Alternatively, MWD-2 could be renamed MWC-2 with a foot note reminding readers of the former label.**

Response:

a. The amended table is included as an addendum to Appendix S in the Draft Final report and will be included at the beginning of Appendix S in the Final report.

b. It will be noted that MWD-2 is actually a C aquifer well; however, the actual well name will remain the same.

14. **Figure 2-1, Flow Chart of Field Activities. While not really a flow chart, the figure is a clear and useful illustration of the general history of site investigation activities.**

Response:

The text and title have been changed to "Chronology of Field Activities."

Chapter 3, Hydrogeologic Conditions

15. **Page 3-2 identifies five stratigraphic zones-A, B, C, D, and E. The Report states "The five zones extend to a depth of 245 feet below the site and apply only to the vicinity of the fenced compound." It is not clear what is meant by "apply only to the vicinity of the fenced compound".**

Recommendation: Definition of site hydrostratigraphy should, at a minimum, encompass all areas of ground water contamination, as well as backgrourd and reinjection areas.

Response:

The text was revised as follows:

> The stratigraphy underlying the site has been divided into five zones—A, B, C, D, and E. These zones are made up of coarse-grained and fine-grained materials. For convenience in discussion, the terms "B," "C," "D," and "E" aquifer have been retained and apply to the permeable units within each specific zone. The five zones extend to a depth of approximately 245 feet below the site. While the depth and thickness of all zones varies within the area of contamination, stratigraphic borings indicate that generally these zones exist as they have been shown in the cross sections in Chapter 4. The conceptual cross section shown in Figure 3-2 indicates the location of these zones beneath the site.

16. **(editorial) The use of "ranges" on page 3-2 to specify depth intervals should be replaced by occurs or extends. Ranges suggests fluctuation or variation. For example, "The transmissivity values range from 100 to 1000 ft^2/day across the site" (page J-17).**

Response:

The word *ranges* was replaced with the word *extends*.

17. **Figure 3-2, Davis Site Conceptual Site Cross Section, and Figure 3-3, Generalized Site Cross Section from MWD-10 to CH-4, could be illustrations of two different sites.**

Recommendation: The conceptual model and generalized cross section should be more consistent with one another.

Response:

Figure 3-2 was revised using portions of Cross Sections A-A',B-B', C-C', E-E', and F-F', so that it would bear a closer resemblance to actual site conditions. Figure 3-3 was also slightly revised.

18. **Pages 3-10 to 3-15 provide an effective discussion and presentation of ground water elevations, gradients and fluctuations that occurred between July 1992 and July 1993.**

Recommendations:

a. **The discussion and graphics should be amended to evaluate available historic elevation and gradient data for consistency with the trends clearly identified in the Report.**

b. **In addition to the MW3 well cluster, vertical gradients should be calculated for well clusters across the site.**

Response:

a. Historical groundwater elevation data will be reviewed, and a discussion of the results of that evaluation will be provided in the Final report. The evaluation will consist of calculating historical gradients and flow directions and checking to identify if any changes have occurred over time.

b. Vertical gradients for additional well clusters will be provided in the Final report.

Chapter 4, Nature and Extent of Contamination

19. **Figure 4-1, Site Base Map; Figure 4-1a, B and C Aquifer Target Areas; and Figure 4-1b, D and E Aquifer Target Areas. These maps provide the only plan view of the distribution of ground water contamination in the Report.**

Recommendations:

a. **Summary tables of SCOCs detected in each well should be provided. For each well, and each sampling event, the tables should illustrate dates of sampling and concentrations of SCOCs detected (or not sampled, or not detected).**

b. **Concentration contour maps illustrating historic contaminant distributions should be compiled as an appendix.**

c. **All of the target areas and concentration contours should be amended to reflect recently obtained data.**

d. **As discussed above, additional maps should be provided so upcoming water quality data can be easily evaluated when made available.**

e. **The figures should be amended to specify sampling dates associated with the data that are contoured.**

f. **The B Aquifer 5 µg/l TCE contour should be illustrated.**

g. **Additional discussion regarding determination of the E Aquifer target area is warranted.**

Response:

a. See response to Comment 6, Volume II of III, from Mark Malinowski.

b. Time concentration plots for each well will be substituted for concentration contour maps for each sampling event (consensus established during the January 5, 1994, teleconference with DTSC and McClellan AFB).

c. All of the target areas have been amended to reflect July 1993 data.

d. Time concentration plots will be produced with additional space left on the time axis for the addition of new data.

e. Figures 4-1a through 4-1d have been changed to reflect current data.

f. The 5-ppb TCE contour is noted on Figure 4-1a.

g. The text has been revised as follows:

The E aquifer target area is based on water quality results from MWE-3, MWE-21, and MWE-22. Sampling results from the E aquifer monitoring wells indicate that volatile organic compound (VOC) concentrations are below the allowable MCL.

20. **Figure 4-2a, Vadose Zone Target Area.**

Recommendation: Concentration contours should be developed to illustrate the distribution of contamination at several depths in the vadose zone.

Response:

Additional figures (overlays) have been added to show concentration contours at 5-, 10- 20-, and 30-foot depths.

21. **Figure 4-7, Davis Site Conceptual Model, illustrates an interpretation of the distribution of subsurface materials that is significantly different than the distribution illustrated on Cross Sections A-A' through J-J'.**

Recommendation: The cross sections and figure should be amended to be consistent with one another.

Response:

Figure 4-7 was revised using portions of Cross Sections A-A',B-B', C-C', E-E', and F-F', so that it would bear a closer resemblance to actual site conditions.

22. **Cross Sections A-A' through J-J' should provide a detailed and accurate illustration of subsurface materials and properties that were measured (or observed) during the site investigation. The cross sections should also present the Contractor's reasonable interpretation of the overall distribution of subsurface materials and contamination at the site.**

Recommendations:

a. **The cross sections should be reviewed and approved by a California registered geologist.**

b. **The proportions and extent of course and fine grained sediments does not appear reasonable and should be reevaluated. Based on the drawings, it appears that site borings intercepted a very high percentage of discrete coarse grained units.**

c. **Assuming that every cross section is bounded on all four sides by "fin-grained material" is not a reasonable interpretation and should be reevaluated.**

d. **Assuming that contamination detected in monitoring wells is as restricted as illustrated is unreasonable.**

e. **Intersections of cross sections should be checked and amended where inconsistencies are found. Examples of items requiring amendment**

include: thickness of aquifers and aquitards (off by factors of greater than two); missing aquifers; and presence and thickness of "course-grained materials", "estimated VOC groundwater contamination" and "estimated vadose zone VOC contamination".

f. Depths below ground surface should not be negative.

g. Changing spacing between wells and/or borings and projecting wells and/or borings should be cautiously applied.

Response:

Cross sections were revised to include the following changes:

a. Reviewed and approved by a California C.E.G.

b. Coarse-grained units now display limited lateral continuity, as expected in a channel deposit. Predominant channel flow direction given in site map for Figures 3-2 and 4-7.

c. See Comment b above.

d. Contamination has been extended throughout screened interval of well.

e. Inconsistencies have been corrected.

f. Depths are now positive.

g. We have added "projection lines" to help alert the reader to changes caused by projecting wells and borings in the cross sections.

Chapter 6, Feasibility Study

23. **On page 6-8, when discussing the B, C, D, and E aquifers, the Report states "The units are not laterally continuous across the site, but generally are separated by finer-grained aquitards." The Report is referring to the A-B, B-C, C-D and D-E aquitards. The description is not consistent with the conceptual model presented earlier in the Report or the computer model used to evaluate aquifer test data. The conceptual model presents the D and E aquifers as laterally continuous across the site. The aquitards are presented as generally dampening vertical flow between the aquifer zones. Additionally, comparison of water level hydrographs illustrating seasonal data from groups of wells indicates that each aquifer zone is more laterally interconnected than vertically connected with other zones. The B and C zones do not follow this pattern.**

Recommendation: The text or the conceptual model should be amended.

Response:

The following sentence was deleted:

> "The units are not laterally continuous across the site, but generally are separated by finer-grained aquitard".

24. **Page 6-18 refers to Appendix J, Groundwater Extraction Evaluation, for discussion and description of water level monitoring to check for hydraulic control during treatment system operation. Appendix J proposes using strategically selected pairs of wells to monitor gradients.**

Recommendation: Initially, water levels should be measured in all site ground water wells and piezometers and ground vater elevation contour maps should be prepared to evaluate hydraulic gradients relative to contaminant distributions.

Response:

The use or well pairs for horizontal and vertical gradient determination allows for measurement of capture in specific directions. It is agreed that all wells should be measured and respective contours should be drawn for each respective aquifer.

25. **Page 6-33 states "If the transmissivities are lower than the ranges cited in the table, additional extraction wells may be needed to attain capture." Table 6-12 repeats the uncertainty. Table 6-13 applies a contingency cost to the uncertainty.**

Recommendation: The concern should be further discussed in the Report. Holding other parameters constant, a lower transmissivity will produce a more extensive capture zone.

Response:

The second paragraph in Section 6.5.1.1 (Aquifer Properties) has been modified to read:

"....If the transmissivities are lower than the ranges cited in the table, additional extraction wells may be needed to attain groundwater capture. This is because the areal extent of capture from a single well decreases with decreasing transmissivity (Freeze & Cherry, 1979)."

26. **Page 6-36 states "If storativity values fall below the ranges cited, additional extraction wells may be needed, or cleanup times may be longer than expected." Table 6-2 repeats the uncertainty. Table 6-13 applies a contingency cost to the uncertainty.**

Recommendation: The concern should be further discussed in the Report. The coefficient of storage is the volume of water produced divided by the change in head and area. Upon achieving some sort of steady state, drawdown ceases and the coefficient of storage becomes relatively unimportant. However, during initial pumping, a lower coefficient of storage will result in less water produced for a given decrease in head.

Response:

The following language has been added to the third paragraph in Section 6.5.1.1:

> "... Storativity is the volume of water that an aquifer releases from storage per unit surface area of aquifer per unit decline in hydraulic head. At steady-state, drawdown ceases, and the storativity becomes relatively unimportant. However, groundwater modeling for the Davis Site indicates that steady-state will not be achieved during groundwater extraction for a long time period (>10 years). Therefore, storativity is a significant aquifer property that will impact groundwater remedial actions."

27. **Page 6-36 states "If the actual vertical permeabilities are lower than those cited, additional extraction wells may be needed."Table 6-2 repeats this uncertainty. Table 6-13 applies a contingency cost to the uncertainty.**

Recommendation: This concern should also be further discussed in the report. If vertical permeabilities are decreased, less water will be contributed from above and below a given aquifer zone and extraction from the zone will be more effective.

Response:

The concern is true that less water will be contributed from above and below a given aquifer zone. This means that a longer groundwater pumping time will be needed to remove contamination from the aquitards. The referenced sentence has been changed as follows:

> "If the actual permeabilities are lower than those cited, additional extraction *time* may be needed to remove contamination from the aquitards."

28. **Page 6-36 identifies uncertainties associated with ground water gradients and notes that gradients vary from year to year while the Report focuses on gradients representing 1992-1993.**

Recommendation: As mentioned in Comment 18, above, it may be prudent to evaluate available historical gradient data to determine if the 1992-1993 trends and ranges are typical of available site data.

Response:

See response to Comment 18a.

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS SACRAMENTO AIR LOGISTICS CENTER (AFSC)
McCLELLAN AIR FORCE BASE, CALIFORNIA

FROM: SM-ALC/JAV

SUBJ: Draft RI/FS, Davis Site

TO: SM-ALC/EMR

1. I have reviewed the draft Remedial Investigation/Feasibility Study Report for the Davis site. I have no legal objection to release of the document. My few comments follow.

2. My principal concern with this exhaustive and well-written report is that it fails to reflect the unique position of the Air Force as the lead agency in our cleanup. I believe the authors have used a plug-in approach for many of these chapters, utilizing discussions from other, previously written products. This is not inappropriate, and I have no objection to it. It is apparent, however, that EPA was usually the lead agency for these earlier efforts, and the discussions when applied to our cleanup need to be fine-tuned. I will illustrate several examples.

a. Volume I, Executive Summary, p viii, 2d full paragraph: The remedial action will be selected by McClellan, and must meet approval by EPA, DTSC, and RWQCB.

b. Volume II, Appendix G, p G-1, 1st full paragraph under "Description of ARARS": Final determination of ARARS is made by AF, not EPA.

c. In the very next paragraph, it states that "EPA may use . . ." It should read "the Air Force may use . . ."

d. At p G-2, 2d paragraph: The second sentence states that ARARS must be timely identified to EPA. It should read that they must be identified to the Air Force.

My review may not have found all the instances where the authors have unthinkingly operated from the assumption that EPA is the lead agency. We should be careful to correct any such instances.

3. Volume I, p 7-3, Table 7-1: For the contaminant methyl isobutyl ketone, the 3d column fails to list a potential remedial approach, which I assume should be ground water extraction.

4. Volume II, Appendix G, p G-11, 2d full paragraph: This discussion refers to a permit issued to our ground water treatment plant. It should note that the permit was not renewed due to our CERCLA permit exemption for on-site activities. Thus, while the permit itself is not an ARAR, the effluent levels referred to in the inactive permit may reflect substantive requirements with which the Air Force must comply.

5. Appendix G, p G-16, Table G-4, Item 16: The cite to 20 CFR 1910.120 should instead by 29 CFR 1910.120.

6. Appendix G, p G-25, top 2 paragraphs: I do not recognize the citations that begin with "R 18-8": I believe the correct citations are to 40 CFR.

7. Volume II, Appendix K, p K-11 (Table K-1), middle column, bottom tier: It states here that "all necessary permits should also be obtainable." No permits would be required for this on site bioventing, and this reference should be removed.

MARTIN KECK
Environmental Counsel

STATE OF CALIFORNIA - Environmental Protection Agency PETE WILSON, Governor

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION
3443 Routier Road, Suite A
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CH2M HILL
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9 December 1993

Ms. Doris Bajka
Environmental Management
SM-ALC/EMR
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McClellan Air Force Base, CA 95652-1389

DRAFT COPY, REMEDIAL INVESTIGATION/FEASIBILITY STUDY REPORT, DAVIS GLOBAL COMMUNICATIONS SITE, MC CLELLAN AIR FORCE BASE

Thank you for the opportunity to review the subject report. Our comments are as follows:

A. Volume 1

1. Target Area for C Aquifer. Figure 4-1a shows the target area for ground water remediation based on data collected from monitor wells prior to March 1993. The additional ground water sampling and analysis on samples collected since that time shows the target zone should be expanded farther to the south. Monitor well PC-21 which is depicted as the outer boundary of the target area was found to have 132 µg/l TCE. Using this data, the target zone for the C aquifer would be expanded significantly and the calculated mass estimate will be much greater. The mass calculations and the target zones should be reevaluated.

   The new ground water data was used to determine if the proposed extraction rates and zones of capture would be sufficient to capture the extent of contamination. To do this, the new target zone would have to have been developed. This new zone should be presented in the draft final version of the report.

2. The Target Area for the D Aquifer. The comment for the C Aquifer Target Area applies in general to that depicted for the D Aquifer on Figure 4-1b. The ground water concentration isocontours should be reconfigured after adding the data from the ground water sample collected from the D zone during the drilling of MWE-21. This data will yield a greater volume and mass of contaminants than that calculated for the report.

3. Vadose Zone Target Area. Though staff agrees generally with the defined target zone, we believe that the data presented in the cross-sections depicts the possibility of a greater target volume at depth than that shown on Figure 4-2a. The shallow soil gas sampling is likely not sufficient to define the extent of soil gas contamination at depth. As part of the last phase of Remedial Investigation field work, some borings and associated soil gas sampling should be included. These borings could be converted to soil gas monitor/extraction wells as necessary. If they are converted to monitor wells they will be useful in determining the zone

of capture of the soil gas extraction system. This point was discussed in your office during the last several weeks.

4. Section 4.2.2, Mass of Contamination. The mass of contaminants in the ground water should be calculated using all the available data. See comments 1 and 2, above.

5. Figure 4-6a. The inert figure should also show the lines for TCE and t-1,2-DCE.

6. Figure 4-16. Similar to the other cross-sections, the vadose zone contamination should be depicted if sufficient data is available completed monitor wells? The results from these wells, sampled in July 1993, should be added to the report.

7. Page 6-6, first paragraph. It is stated that there should be no need to install additional wells for monitoring purposes. As stated above, staff is not of the opinion that the extent of deeper contamination in the soil gas has been determined. In addition, there may need to be additional monitor wells to determine the effective radius of capture of the extraction system.

8. Figure 6-5. The extraction wells for the D aquifer should be moved as discussed during our recent teleconference.

9. Table 7-1. It is listed in this table that the semivolatile organic contaminants will be potentially remediated at the site by bioventing. Has this method been shown effective on the semivolatile contaminants?

10. Chapter 7, Conclusions. Conclusions should be revised based on the above comments.

B. Volume 2

1. Appendix F. Data from the newly installed ground water monitor wells should be included in this appendix to show ground water contaminant contours and development of mass estimates. The latest data may alter the presented values to some extent.

2. Appendix F, figure F(a)-1. With the presented data for concentrations in the C Aquifer, the C Aquifer target area appears to extend to far to the northwest. The same thing can be said for the D Aquifer target volume as delineated in Figure F(a)-2.

3. Appendix F, page F-23. It is stated that in the conclusions that the extent of contamination in the vadose zone is based on the results of the shallow soil gas survey. Those results may not be indicative of the contamination at depth. The target area needs further definition with deeper soil gas sampling.

4. Appendix F. Pages F-22 through F-24 are repeated as F-26 through F-28.

5. Appendix F, page F-29. It is stated that the organic fraction value used in the analyses was based on sample results and is considered a fair representation of the site values. Only one

sample was analyzed for organic carbon content. It may or may not be representative of the site, but is better than using a book value.

6. Appendix G, page G-10, sixth paragraph. The Basin Plan for the Central Valley Region establishes the beneficial uses of specific water bodies within our region. The *Inland Surface Waters Plan* establishes water quality objectives for receiving waters to protect aquatic life and sources of drinking water from various pollutants.

7. Appendix G, paragraph 2. The permit for the discharge from the Ground Water Treatment Plant at McClellan AFB is not an ARAR for the Davis Transmitter Site. It is, however, an example of the limitations that might be placed on a similar discharge from the a Davis site ground water extraction and treatment discharge. The regulations used to develop the McClellan AFB permit would be the same as those that would be applied to the Davis site.

8. Table G-6. This table of ARARs should include the California Water Code for discharge of wastewater effluent from the treatment plant. Cleanup values for the vadose zone and ground water must comply with SWRCB Resolution 68-16 as an ARAR, with Resolution 92-49 as a TBC. Chapter 15 does not apply to the discharge from the treatment plant to a surface water.

9. Appendix G, page G-30, first paragraph. Cleanup of soils and ground water to background concentrations, unless proven technically and economically infeasible, is required in Resolution 68-16 and Title 23, Division 3, Chapter 15.

10. Appendix J, Figure J-19. The first decision diamond on the right side of the flow diagram does not have a "Yes" path associated with it. Two other decision diamonds have two arrows leading from them but only the "no" path is delineated.

    The first box on the right side states that the extraction wells should be each sample and composited. Why not just sample the influent to the treatment system to determine mass loading to the treatment system. A certain frequency of sampling the individual extraction wells for separate analysis should also be postulated.

11. Appendix M, Costs for treatment options. The section was improved over the working copy. Some minor changes are still needed as follows:

    a. Labor costs for GAC are twice as high as those for the other treatment options even with the same number of hours.

    b. Why is the cost of additional labor more for TV1 GAC than for TV2 even though the same number of hours are required?

    c. Why are there twice as many samples for TV2 as TV1?

    d. Table M(a)-7. The O&M costs listed for GAC TV2 appear to be in error.

Please use these comments during development of the draft final version of the report. If you have any comments regarding this matter, please call me at (916) 255-3025.

ALEXANDER MACDONALD
Project Engineer

cc: Mr. Mark Malinowski, Dept. of Toxic Substances Control, Sacramento
Mr. Gerald Vogt, CH_2M-Hill, Redding

STATE OF CALIFORNIA—ENVIRONMENTAL PROTECTION AGENCY PETE WILSON, Governor

ARTMENT OF TOXIC SUBSTANCES CONTROL
...ON 1
10151 CROYDON WAY, SUITE 3
SACRAMENTO, CA 95827-2106
(916) 255-3717

December 15, 1993

Mr. Jerry Styles
SM-ALC/EMR
5050 Dudley Boulevard, Suite 3
McClellan AFB, California 95652-1036

Dear Mr. Styles:

Enclosed are the Department of Toxic Substances Control's (Department) comments on the Davis Global Communications Site (Davis Site) Draft Remedial Investigation/Feasibility Study Report (RI/FS Report), dated November 1, 1993. The comments have been coordinated with the Central Valley Regional Water Quality Control Board.

Also enclosed are the Department's comments on the Davis Site Draft Risk Assessment.

All comments should be responded to on a point-by-point basis and added as an appendix to the appropriate document.

If you have any questions or comments regarding this matter, please contact me at (916) 255-3717.

Sincarely,

Mark Malinowski
Associate Engineering Geologist
Site Mitigation Branch

Enclosures

cc: Mr. Alex MacDonald
Central Valley Regional Water
Quality Control Board
3443 Routier Road, Suite A
Sacramento, California 95827-3098

Mr. Tom To
Director of Environmental Health
Yolo County Environmental Health Services
10 Cottonwood Street
Woodland, California 95695

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12-20-93 11:17AM FROM DTSC/REGION 1 TO 96430827 P002
12/21/93 12:13 ENVIRONMENTAL RESTORATION NO.854 D02

Department of Toxic Substances Control's Comments
on the Davis Site Draft
Remedial Investigation/Feasibility Study Report
dated November 1, 1993

Volume I of III

General Comments

1. The report is well written and organized. The groundwater mass and volumes should be updated to include the most recent groundwater sampling data.

2. Given the screen interval, monitoring well MWD-2 should be re-labeled as MWC-2.

3. When metric weights (kg) are provided, also include the U.S. customary weights (pounds or ounces).

4. The monitor well Concentration versus Time plots should use a log scale along the concentration axis. The log scale provides better resolution at low concentrations.

Specific Comments

	Pg	Sec	Pgph	Comment
1.	iii		4	Specify the vadose zone "objectives."
2.	viii			Conclusions The Executive Summary Conclusions should summarize the short narratives presented in Chapter 7 (e.g., vadose zone contamination will continue to contaminate groundwater if action is not taken. VOC contamination continues to spread downward and outward. SVE would reduce VOC mass in the vadose zone adequately and prevent continued contamination of the groundwater. Groundwater containment systems would inhibit off-site migration of groundwater.)
3.	xvii			Glossary of Terms Please define the following: anaerobic dehalogenation - halogen, biotransformation - chlorinated alaphitic.

	Pg	Sec	Pgph	Comment
22.	6-11	6.2.4.3		Include a paragraph describing the need to drill exploratory holes to ensure reinjection is viable (technically, i.e., aquifer capability, regulatory i.e., groundwater quality between injected water and aquifer water.)
23.	6-35	Table 6-12		The Target Areas should be volumes. Estimates for groundwater should be provided in some measure appropriate for water (e.g. gallons or acre fee.) The Vadose Zone Target Area (Volume) should be in cubic feet.
24.				Mass of Contamination is underestimated due to a lack of understanding/measuring contaminant adsorption to soils.
25.	6-39	Table 6-14		Include the costs for capturing contamination that exceeds 10^{-6} risk.
26.	7-2	7.3	1	Include the State of California's Non-Degradation requirements in this section as a reason for taking action.
27.	7-2	7.5		Include additional "deep" soil gas sampling.

Volume II of III

1.	B-2			Provide a map showing the five SVMWs and nine piezometers locations. Specify the dates of the tests and the most recent rainfall event and amount of precipitation.
2.	Fig B-2			The response of the SVMWs and piezometers are suspiciously matched to the barometric pressure. Can you provide any insight to the correlation? The data for the air permeability tests at CH-1 and 5 do not appear to correlate as closely.
3.	B-17		1	Is it possible that the biological activity (no measured oxygen) caused the positive pressure observed in the CH-5 well?

	Pg	Sec	Pgph	Comment
4.	1-4	1.2	3	The reference to Figure 1-3 as a "timeline for remedial investigative activities" is not accurate. Figure 1-3 indicates only the contractors who worked on the site, not the work performed. Is Figure 1-3 missing verbiage on the right hand side that would indicate the contractor's efforts? (e.g., Kleinfelder - UST investigation., ITC - RI work - determine extent of groundwater contamination., Radian - quarterly groundwater sampling., etc.) Radian did perform some groundwater sampling in 1988.
5.	1-4	1.3.1		Include the main objective of the RI; gather enough information to be able to conduct a feasibility study, perform a remedial design and implement a clean-up action.
6.	4-3	4.2		The contaminant mass estimates and target volumes should be revised based on the most recent sampling results.
7.	4-3	4.2.1		Selection of Target Areas should include estimated groundwater target volumes (total gallons) for each zone. Groundwater volumes for non-detect, MCL and 10^{-6} risk boundaries should be presented (Table format would probably be best.)
8.	Fig.	4-6(a-h)		The Department recommends using a log scale for the concentration plots. Plots for all the monitoring wells at the site should be included as an appendix.
9.	Fig.	4-9		Intersection identified as G-G' should be H-H'. Contamination (red) should be depicted in PC-21, and extended from MWE-3 to MWE-21. Contamination should be illustrated throughout (vertically) the aquifer that is screened (see MWD-3). Contamination should be shown across the screened section of MWC-3. Explain the contamination indicated between MWC-3 and MWD-3.
10.	Fig.	4-10		Indicate the H-H' cross section intersection. FW-1C has been ND in 7/93 and 10/93. Contamination should not be shown in the C zone in this cross section.
11.	Fig.	4-11		Contamination should be shown in MWE-22.

	Pg	Sec	Pgph	Comment
12.	Fig.	4-12		Provide the sampling results for MWC-1 and MWD-1.
13.	Fig.	4-13		Sampling results from 7/93 for EW-1C and MWD-2 do not support the contamination depicted in the C aquifer. The contamination in the B zone should extend east, past MWB-13.
14.	Fig.	4-14		Provide the sampling results for MWC-4.
15.	Fig.	4-16		Groundwater contamination should be depicted southwest past EW-3C (B zone), and MWD-10 (D zone), and northeast past MW-6 (B zone). As previously stated, the C zone sampling data do not support the contamination depicted. It appears that contamination is migrating downward, from the B to the C, near the MW(X)-3 cluster. Include the 7/93 data for MWE-3.
16.	Fig.	4-17		Contamination should be depicted in the E zone.
17.	5-5	5.3		The "clean-up levels" for groundwater are actually "targets levels." This section should indicate that the FS evaluates the cost to clean-up groundwater to background, MCLs and 10^{-6} risk.
18.	6-6		1	Additional soil gas monitoring/extraction wells should be considered to evaluate the subsurface zone that is saturated in the winter, but dewatered in the summer.
19.	6-6	6.2.3.2		Does the site have a natural gas line? If not, have the additional costs to install a gas line been incorporated into the CatOx cost evaluation?
20.	6-8	6.2.4		The FS should use the target volumes generated in Chapter 4, and evaluate the cost to clean-up groundwater to background, MCLs and 10^{-6} risk. Use of the term Target Volume for groundwater is inaccurate since no volumes are presented
21.	6-9	Fig. 6-5		The figure should be revised to indicate the location of the extraction wells based on the November, 1993 teleconference between CH2M Hill, McAFB, the RWQCB and DTSC.

	Pg	Sec	Pgph	Comment
4.	B-17			Recommendations are not supplied. Are additional SVE wells needed? Will additional testing be needed prior to installing SVE wells? Will the existing wells be adequate for performing SVE or should larger diameter wells be installed? Should air permeability tests be conducted in the summer and winter to evaluate the impact of soil moisture and level of groundwater? Would soil moisture profiles be helpful in evaluating the air permeability results? Will larger diameter SVE wells have any significant effect on the radius of influence?
5.	D-4		1	Field Exploration Have owls been observed in the soil piles? The data for samples from the northern and eastern soil piles could not be found in Table U-1.
6.	E-1			Provide concentration plots for all wells. Use the same scale (log) for all the wells. Provide tables, like J-1, for all the sampling episodes. Include groundwater elevations and detection limits.
7.	G-1		2	The Davis site is a State Lead site. The EPA will not make the final determination of ARARs, as specified.
8.	I-1			If SVE is viable for the interval between 40 feet bgs and the lowest (summer) seasonal water table, a section should be added to discuss the advantages and disadvantages.
9.	Fig. J-19			AG pumping Diamond - Define a time period (i.e. 2-3 weeks). Adjust Q Box - It may not be necessary to adjust "all" well(s). The logic for the two "Adjust Target Area" Diamonds is not clear. What is the difference between the McAFB adjust treatment box and the previous adjust treatment decision diamond and why does the McAFB adjust treatment box lead into another adjust treatment diamond? The "No" direction "clean-up criteria met?" diamond, should flow to all three decisions, "adjust target area?", "adjust treatment?" and "adjust monitoring frequency?". After the first quarter, how often will influent be sampled?

12-20-93 11:17AM FROM DTSC/REGION 1 TO 96430827 P007
12/21/93 12:15 ENVIRONMENTAL RESTORATION NO. 854 D07

	Pg	Sec	Paph	Comment
10.	L-4			Gas Phase Carbon Adsorption. The Department recommends further discussion of the non-regenerative carbon DREs, as well as advantages and disadvantages. As described on page L-14, the Department would like McAFB to consider that the vinyl chloride (and probably methane) concentrations will drop rapidly after operation of an SVE system - reference OU-D SVE at McAFB. A small temporary CatOx unit may be adequate for initial operation. After vinyl chloride and methane concentrations drop, the carbon units would be effective in controlling off-gas emissions and cheaper to operate and maintain.
11.	L-5			Operation data at McAFB indicate that the Purus Padre system does, in fact, "capture" vinyl chloride.
12.	L-8			Screening Methodologies. Provide a more complete description of how the ranking was completed. In Table L-3 the Operational Costs: Carbon Adsorption = 4 (21,500); CatOx = 10 (28,000). Capital Costs: Carbon = 10 (19,300); CatOx = 3 (67,000). The Department would suggest that if the Carbon Operational rank is 4, yet it is less expensive than CatOx, how can CatOx receive a 10? If Carbon had a ranking of 10, carbon and CatOx would rank equally.
13.	L-10	Table L-2		CatOx. To ensure accurate capital cost, ensure that a natural gas line hook up is included in the cost. It is possible that the site does not have natural gas run to the site.
14.	L-11	Table L-3		The weighted rank scores for Carbon's Status Development, Feed Variability and Problem Compounds, should be corrected. The Weighted Total score is 735, unless the ranking for Operating costs are re-evaluated (see above comment.)

12-20-93 11:17AM FROM DTSC/REGION 1 TO 96430827 P008
12/21/93 12:15 ENVIRONMENTAL RESTORATION NO.854 D08

	Pg	Sec	Paph	Comment
15.	L-13		3	Paragraph 3 states that given the low concentrations of contaminants, CatOx treatment is a "gross waste of energy..." and recommends another treatment technology. In **Recommendations and Conclusions** the only option for off-gas treatment (SVE and groundwater) is CatOx. The Department staff recognizes the need to acknowledge the apparent contradiction but suggests toning down the statement in paragraph 3.
16.	M-2		2	**Groundwater Flows** Clarify the first sentence. It is unclear what is meant by "... they will add insufficient difficulties to the treatment capabilities."
17.	O-1		1	Edit. It is assumed that the "intermittent capillary zone" refers to the "fine grained soil within..." and not to the Davis Site.

12-20-93 11:17AM FROM DTSC/REGION 1 TO 96430827 P009
12/21/93 12:16 ENVIRONMENTAL RESTORATION NO.854 D09

(916) 255-3692

M E M O R A N D U M

TO: Mark Malinowski
Associate Engineering Geologist
Site Mitigation Branch

FROM: Mark D. Vest, R.G. Mark D Vest
Associate Engineering Geologist
Base Closure Branch

DATE: DRAFT, December 15, 1993

SUBJECT: Davis Global Communications Site, Draft Remedial Investigation/Feasibility Study Report, November 1993

In response to your request, I have reviewed hydrogeologic aspects of the Draft Remedial Investigation/Feasibility Study for the Davis Global Communications Site (Report). The November 1993 Report was prepared by CH2M HILL (Contractor) for the U. S. Air Force. The following comments and recommendations are based on my review of the Report and are provided for your information and use.

COMMENTS AND RECOMMENDATIONS

General

1. No "fatal flaws" were identified.

2. To support design, construction, and testing of a ground water containment and extraction system, certain maps and cross-sections should be amended to better illustrate that a sound understanding of the distribution of subsurface sediments and contaminants has been achieved.

3. Tabular summaries of analytical data should be provided to support the illustrated distribution of contamination.

4. As per the California Business and Professions Code, a sign-off should be provided by California registered geologist indicating responsibility for all geologic content of Report.

12-20-93 11:17AM FROM DTSC/REGION 1 TO 96430827 P010
12/21/93 12:16 ENVIRONMENTAL RESTORATION NO.854 P10

Executive Summary

5. The Report states (p. iii) "...this report does not address hydrocarbon contamination as a portion of the remedial action."
Recommendation

The Contractor should discuss any likely effects on operation of a ground water extraction and treatment system resulting from diesel constituents inadvertently recovered with volatile contaminants.

6. (Editorial) The Report states (p.iv) "Groundwater modeling results were performed to verify...." It is not clear what is meant by, "results were performed".

7. Also on page iv, the Report mentions ground water analytical data that became available relatively late in the report preparation period.

Recommendation

a. Ongoing collection and interpretation of data should be anticipated.

b. Summary tables, graphs, maps and cross sections should be developed with space reserved to add late breaking data.

c. The actual insertion of late breaking data into tables and graphics can be performed by the Contractor or by users of the documents.

Chapter 1, Introduction

8. On page 1-1, the Report discusses ground water contaminant data that became available relatively late during preparation of the Report. The Report states "These data were incorporated into site cross sections... and into the site groundwater modeling in Appendix J. Groundwater modeling was performed to verify that July 1993 data do not significantly impact the recommendations provided in this report."

Recommendations

a. Refer to comment 7, above.

b. The Report should briefly specify what additional ground water modeling was performed using the July data.

9. On page 1-2, the Report further discusses separating remediation of the zone of diesel contamination from the VOC remediation.

Recommendation

Refer to comment 5, above. The Contractor should decide if diesel constituents are likely to effect extraction or treatment system operation.

10. (editorial) Page 1-4 states "The Davis Site consists of the fenced, Main Compound Area (approximately 9 acres), communication antennas, and undeveloped grasslands (as shown in Figure 1-2)". Except for the fenced compound area, the figure does not show these features.

Recommendation

The text and/or figure should be amended to be consistent with one another.

11. Page 1-8 provides three criterion that were used to develop contaminants of concern (COCs). Table 1-1, Contaminants of Concern, lists the COCs.

Recommendation

The table should be amended to include an additional column specifying which criteria from page 1-8 led to inclusion of each compound in the list of COCs.

12. A note at the base of Table 1-1 identifies a criterion to identify a "contaminant of potential concern".

Recommendation

The Report should discuss the significance of the note and contaminants of potential concern.

Chapter 2, Field Investigation Activities

13. Page 2-8, Table 2-2, Well Construction Data.

Recommendations

a. An amended version of the table should be provided as part of Appendix S, Well Construction Data. In addition to the information provided on Table 2-2, the amended table should include well location, borehole diameter, total depth, drilling method, filter pack size gradation and interval, and surface completion type.

b. MWD-2 should be listed with the C Aquifer wells. A foot note should be provided to explain the MWD label. Alternatively, MWD-2 could be renamed MWC-2 with a foot note reminding readers of the former label.

14. Figure 2-1, Flow Chart of Field Activities. While not really a flow chart, the figure is a clear and useful illustration of the general history of site investigation activities.

Chapter 3, Hydrogeologic Conditions

15. Page 3-2 identifies five stratigraphic zones-A, B, C, D, and E. The Report states "The five zones extend to a depth of 245 feet below the site and apply only to the vicinity of the fenced compound." It is not clear what is meant by "apply only to the vicinity of the fenced compound".

Recommendation

Definition of site hydrostratigraphy should, at a minimum, encompass all areas of ground water contamination, as well as background and reinjection areas.

16. (editorial) The use of "ranges" on page 3-2 to specify depth intervals should be replaced by occurs or extends. Ranges suggests fluctuation or variation. For example, "The transmissivity values range from 100 to 1000 ft^2/day across the site" (page J-17).

17. Figure 3-2, Davis Site Conceptual Site Cross Section, and Figure 3-3, Generalized Site Cross Section from MWD-10 to CH-4, could be illustrations of two different sites.

12-20-93 11:17AM FROM DTSC/REGION 1 TO 96430827 P013
12/21/93 12:17 ENVIRONMENTAL RESTORATION NO. 854 P13

Recommendation

The conceptual model and generalized cross section should be more consistent with one another.

18. Pages 3-10 to 3-15 provide an effective discussion and presentation of ground water elevations, gradients and fluctuations that occurred between July 1992 and July 1993..

Recommendations

a. The discussion and graphics should be amended to evaluate available historic elevation and gradient data for consistency with the trends clearly identified in the Report.

b. In addition to the MW3 well cluster, vertical gradients should be calculated for well clusters across the site.

Chapter 4, Nature and Extent of Contamination

19. Figure 4-1, Site Base Map; Figure 4-1a, B and C Aquifer Target Areas; and Figure 4-1b, D and E Aquifer Target Areas. These maps provide the only plan view of the distribution of ground water contamination in the Report.

Recommendations

a. Summary tables of SCOCs detected in each well should be provided. For each well, and each sampling event, the tables should illustrate dates of sampling and concentrations of SCOCs detected (or not sampled, or not detected).

b. Concentration contour maps illustrating historic contaminant distributions should be compiled as an appendix.

c. All of the target areas and concentration contours should be amended to reflect recently obtained data.

d. As discussed above, additional maps should be provided so upcoming water quality data can be easily evaluated when made available.

e. The figures should be amended to specify sampling dates associated with the data that are contoured.

f. The B Aquifer 5 ug/l TCE contour should be illustrated.

g. Additional discussion regarding determination of the Z Aquifer target area is warranted.

20. Figure 4-2a, Vadose Zone Target Area.

Recommendation

Concentration contours should be developed to illustrate the distribution of contamination at several depths in the vadose zone.

21. Figure 4-7, Davis Site Conceptual Model, illustrates an interpretation of the distribution of subsurface materials that is significantly different than the distribution illustrated on Cross Sections A-A' through J-J'.

Recommendation

The cross sections and figure should be amended to be consistent with one another.

22. Cross Sections A-A' through J-J' should provide a detailed and accurate illustration of subsurface materials and properties that were measured (or observed) during the site investigation. The cross sections should also present the Contractor's reasonable interpretation of the overall distribution of subsurface materials and contamination at the site.

Recommendations

a. The cross sections should be reviewed and approved by a California registered geologist.

b. The proportions and extent of coarse and fine grained sediments does not appear reasonable and should be reevaluated. Based on the drawings, it appears that site borings intercepted a very high percentage of discrete coarse grained units.

c. Assuming that every cross section is bounded on all four sides by "fine-grained material" is not a reasonable interpretation and should be reevaluated.

d. Assuming that contamination detected in monitoring wells is as restricted as illustrated is unreasonable.

e. Intersections of cross sections should be checked and amended where inconsistencies are found. Examples of items requiring amendment include: thickness of

aquifers and aquitards (off by factors of greater than two); missing aquifers; and presence and thickness of "coarse-grained materials", "estimated VOC groundwater contamination", and "estimated vadose zone VOC contamination".

f. Depths below ground surface should not be negative.

g. Changing spacing between wells and/or borings and projecting wells and/or borings should be cautiously applied.

Chapter 6, Feasibility Study

23. On page 6-8, when discussing the B, C, D, and E aquifers, the Report states "The units are not laterally continuous across the site, but generally are separated by finer-grained aquitards." The Report is referring to the A-B, B-C, C-D and D-E aquitards. The description is not consistent with the conceptual model presented earlier in the Report or the computer model used to evaluate aquifer test data. The conceptual model presents the D and E aquifers as laterally continuous across the site. The aquitards are presented as generally dampening vertical flow between the aquifer zones. Additionally, comparison of water level hydrographs illustrating seasonal data from groups of wells indicates that each aquifer zone is more laterally interconnected than vertically connected with other zones. The B and C zones do not follow this pattern.

Recommendation

The text or the conceptual model should be amended.

24. Page 6-18 refers to Appendix J, Groundwater Extraction Evaluation, for discussion and description of water level monitoring to check for hydraulic control during treatment system operation. Appendix J proposes using strategically selected pairs of wells to monitor gradients.

Recommendation

Initially, water levels should be measured in all site ground water wells and piezometers and ground water elevation contour maps should be prepared to evaluate hydraulic gradients relative to contaminant distributions.

25. Page 6-33 states "If the transmissivities are lower than the ranges cited in the table, additional extraction wells may be needed to attain capture." Table 6-12 repeats the

uncertainty. Table 6-13 applies a contingency cost to the uncertainty.

Recommendation

The concern should be further discussed in the Report. Holding other parameters constant, a lower transmissivity will produce a more extensive capture zone.

26. Page 6-36 states "If storativity values fall below the ranges cited, additional extraction wells may be needed, or cleanup times may be longer than expected." Table 5-2 repeats the uncertainty. Table 6-13 applies a contingency cost to the uncertainty.

Recommendation

The concern should be further discussed in the Report. The coefficient of storage is the volume of water produced divided by the change in head and area. Upon achieving some sort of steady state, drawdown ceases and the coefficient of storage becomes relatively unimportant. However, during initial pumping, a lower coefficient of storage will result in less water produced for a given decrease in head.

27. Page 6-36 states "If the actual vertical permeabilities are lower than those cited, additional extraction wells may be needed." Table 6-2 repeats this uncertainty. Table 6-13 applies a contingency cost to the uncertainty.

Recommendation

This concern should also be further discussed in the report. If vertical permeabilities are decreased, less water will be contributed from above and below a given aquifer zone and extraction from the zone will be more effective.

28. Page 6-36 identifies uncertainties associated with ground water gradients and notes that gradients vary from year to year while the Report focuses on gradients representing 1992-1993.

Recommendation

As mentioned in Comment 19, above, it may be prudent to evaluate available historic gradient data to determine if the 1992-1993 trends and ranges are typical of available site data.

12-20-93 11:17AM FROM DISC/REGION 1 TO 96430827 P017
12/21/93 12:19 ENVIRONMENTAL RESTORATION NO.854 P17

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Loren Krook/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Soil Gas Investigation
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.18

Purpose and Scope

The purpose of this technical memorandum is to provide the results of soil gas remedial investigation efforts at the Davis Global Communications Site (Davis Site). Interpretation of the data is provided in the Remedial Investigation/Feasibility Study (RI/FS) report.

The three RI soil gas sampling efforts that were conducted included the following:

- **Dry or Partially Submerged Groundwater Monitoring Well Sampling**—On August 24, 1992, soil gas samples were collected from four dry or partially submerged groundwater monitoring wells. The samples were analyzed for volatile organic compounds (VOCs) and selected atmospheric gases at an offsite laboratory.

- **Shallow Soil Gas Survey**—From September 15 to October 6, 1992, a shallow soil gas survey was conducted. A total of 71 soil gas samples were collected from probes driven into the ground to depths ranging from 5 to 20 feet below ground surface (bgs). The samples were analyzed for selected VOCs in an onsite mobile laboratory. Ten of the samples also received confirmational analyses at an offsite analytical laboratory.

- **Soil Vapor Monitoring Well Sampling**—On December 17, 1992, soil vapor samples were collected from 10 soil vapor monitoring wells (SVMWs) and piezometers. Additional samples were collected from three deep piezometers on August 8, 1993. The samples were analyzed for VOCs and selected atmospheric gases at an offsite analytical laboratory.

The following sections provide descriptions of sample locations and depths, sampling equipment and procedures, analytical methodologies, and summary results of laboratory analyses for the two investigations.

Detailed laboratory reports are not provided in this technical memorandum. Complete data packages are available from CH2M HILL in Redding, California.

Background

Several previous investigations have been conducted at the Davis Site. These investigations have involved soil excavation and removal of underground diesel fuel storage tanks, soil borings for contaminant characterization, a soil organic vapor survey, cone penetrometer surveys, in situ groundwater sampling, groundwater monitoring well installations and sampling, and evaluation of stratigraphic and hydrogeologic characteristics of the site. These investigations have continued from 1981 to the present.

This technical memorandum will limit discussion of previous investigations to those relevant to the soil gas sampling and analyses performed as part of the current remedial investigation efforts. Additional site background information, descriptions, and site characterization information can be found in Section 2.0 of the Draft Final Work Plan, Davis Global Communications Site Remedial Investigation (CH2M HILL, 1992a).

Previous Investigations

The relevant previous investigation at the Davis Site was performed by International Technology Corporation (ITC) from April 3 to April 19, 1989. In this investigation, a shallow soil gas survey was conducted. The objectives of this survey were:

- To determine the extent of volatile organic vapor contamination to a depth of 10 feet bgs
- To determine the prevalence of target compounds trichloroethene (TCE), tetrachloroethene (PCE), vinyl chloride (VCL), and benzene in the soil vapors
- To determine the locations for future cone penetrometer and soil borings

During the soil gas survey, 94 locations were sampled on a 40-foot by 40-foot square grid. Soil gas probes were driven 10 feet bgs and soil vapor samples extracted. Concentrations of total volatile organic compounds (TVOCs) were measured using a photoionization detector (PID). Samples with PID readings greater than 1 part per million volume (ppmv) were also analyzed in the field using a gas chromatograph

(GC). Target compounds for GC analysis included TCE, PCE, vinyl chloride, and benzene.

Detection limits during GC analyses are shown in Table A-1.

Table A-1
Detection Limits During GC Analyses

Target Compound	Detection Limit (ppbv)
Trichloroethene	22.3
Tetrachlorethene	160.5
Vinyl Chloride	106.0
Benzene	28.5

The results of the soil gas survey identified PCE and TCE plumes in the vadose zone at a depth of 10 feet bgs. Figure A-1 shows the extent of PCE and TCE contamination developed by ITC (1992), based on GC data. Following evaluation of the data, an additional investigation was determined to be necessary to adequately characterize the nature and extent of vadose zone contamination. These additional investigations, including soil gas sampling of dry or partially submerged groundwater monitoring wells, a supplemental shallow soil gas survey, and SVMW sampling, were conducted as part of the Davis Site RI and are the primary subjects of this technical memorandum.

Field Exploration

This section describes the procedures and equipment used during the RI soil gas investigation. Shallow soil gas and SVMW sampling were conducted in accordance with Sections 5.0 and 11.0, respectively, of the Draft Final Davis Global Communications Site Remedial Investigation Sampling and Analysis Plan (SAP) (CH2M HILL, 1992b). The following paragraphs describe the three soil gas sampling efforts conducted at the site: sampling of existing dry or partially submerged groundwater monitoring wells, shallow soil gas sampling, and sampling of SVMWs installed as part of the RI fieldwork.

Dry Groundwater Monitoring Well Sampling

The first phase of the RI soil gas investigation was conducted on August 24, 1992. This part of the investigation consisted of sampling soil vapors from four existing dry or partially submerged groundwater monitoring wells. The wells sampled included MW-1, MW-3, MW-5, and MW-7.

Each of the groundwater wells were modified to function as a SVMW. These modifications consisting of fitting airtight well caps to the top of each well casing. The caps

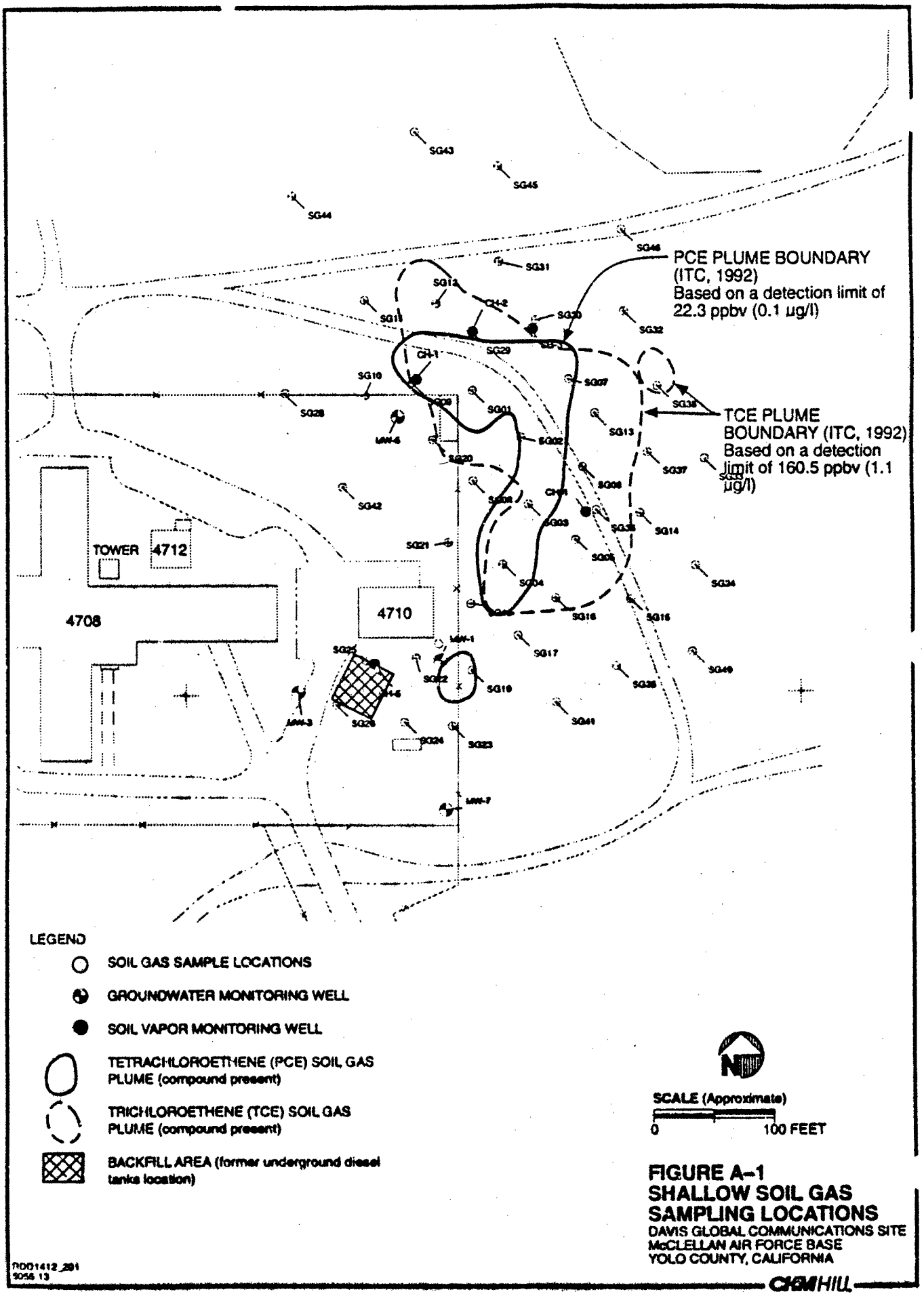

FIGURE A–1
SHALLOW SOIL GAS SAMPLING LOCATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

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were rigged with tubing connectors for purging and sampling. Prior to sampling, each well was purged of 3 well volumes using a vacuum pump. Soil vapor samples were then collected in evacuated 6-liter stainless steel canisters.

Shallow Soil Gas Sampling

Shallow soil gas sampling locations were determined primarily on the results of the previous shallow soil gas survey conducted by ITC in April 1989. The results of this survey identified PCE and TCE plumes at a depth of 10 feet bgs using PID and on-site GC analyses. Figure A-1 shows the PCE and TCE plumes identified by ITC and the locations sampled during the September 1992 shallow soil gas investigation.

Sampling Locations and Depths

A total of 71 soil gas samples were collected at various locations and within and outside the Main Compound perimeter fence. A total of 67 samples were collected for the purpose of defining the horizontal and vertical extent of VOC contamination in the area of the ITC shallow soil gas survey. Four additional samples were collected around the perimeter of Building 4708 for risk assessment purposes. Table A-2 summarizes the number and depths of samples that were planned in the Draft Final Work Plan (CH2M HILL, 1992a) and those actually collected during the field investigation.

Table A-2
Numbers and Depths of Shallow Soil Gas Samples

Sample Depth (feet bgs)	Number of Samples	
	Planned	Actual
5	15	15
10	35	43
13[a]	0	1
17[a]	0	1
20	11	11
Total	67	71

[a]Attempted 20 feet bgs sample terminated because of refusal conditions.

Because of the soil conditions encountered, the sample probe could not be driven below approximately 20 feet bgs. In lieu of these samples, additional samples were collected at 10 feet bgs.

Sampling Equipment and Procedures

Hydro Geo Chem, Incorporated, based in Tuscon, Arizona, collected and analyzed shallow soil gas samples. CH2M HILL supervised the work and determined sampling locations and depths.

Shallow soil gas samples were collected using a customized Ford pickup truck equipped with a hydraulically driven hammer to advance sampling probes below the ground surface. The sampling mechanism consisted of a hydraulically powered friction wheel lifting a 300-pound drop-hammer over a vertical distance of about 3 feet. The impact of the hammer drove 1-3/8-inch outside diameter, nickel-plated, stainless steel extraction well drill rods into the ground. The probes were fitted with detachable high-carbon steel drive points to penetrate the soil.

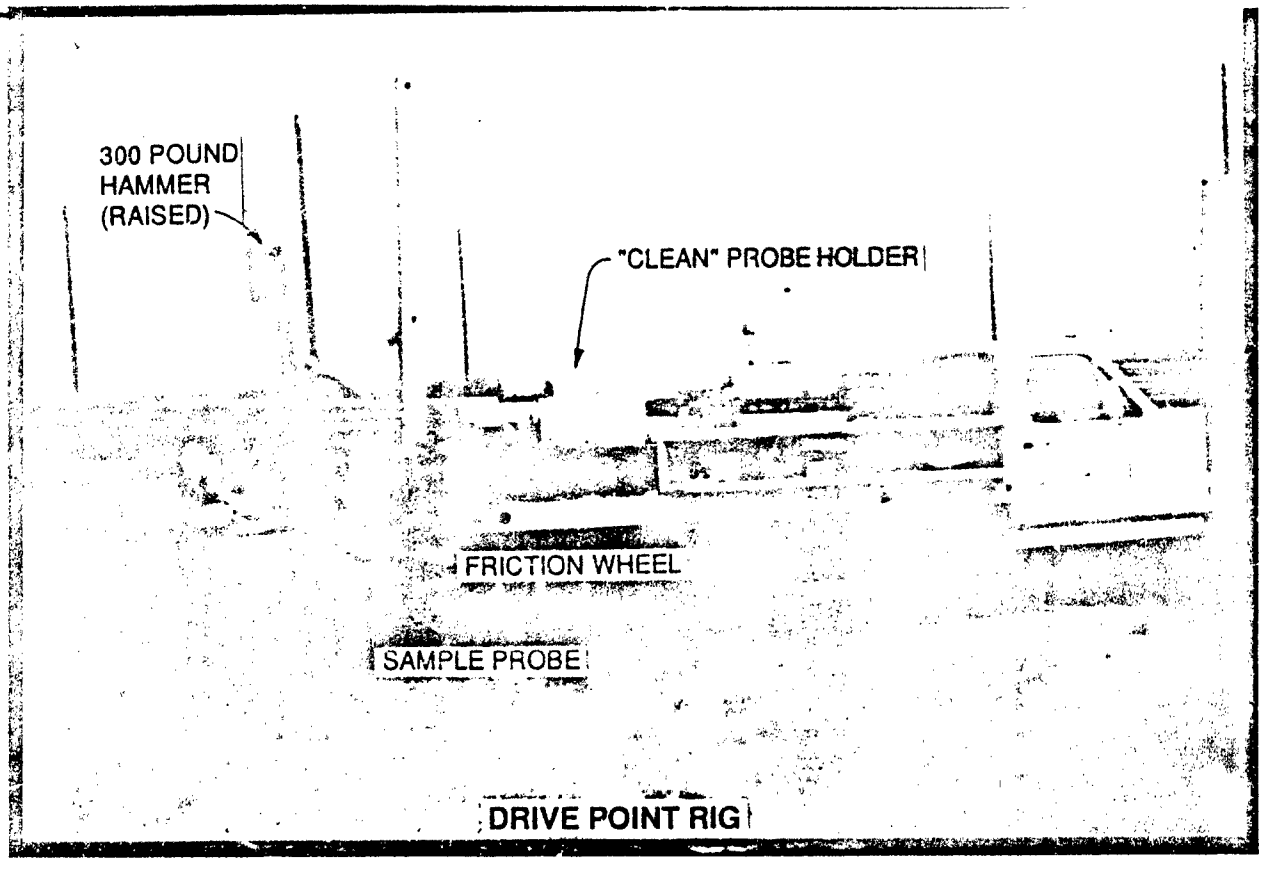
After a soil gas probe had been driven to the required depth, the probe was pulled up approximately 6 inches to 1 foot using the truck hydraulics. As the probe was retracted from the ground, the steel drive point detached from the bottom end of the probe. A pressure-regulated vacuum pump was then attached to the surface end of the probe via a stainless steel adapter. Three to five probe volumes were purged by the vacuum pump to ensure a representative soil gas sample.

Figure A-2 shows the major elements of the field sampling effort.

Onsite Analysis Samples

Samples for onsite analyses were collected by withdrawing soil gas from the vadose zone through an inline sample collection cartridge. The sample cartridge was connected in the sampling train between the probe adapter and the sampling pump. VOCs were trapped and concentrated in a glass tube (Supelco) contained within the stainless steel cartridge. The cartridge was packed with three types of adsorptive, hydrophobic activated carbon to trap different species of VOCs. Carbotrap was used to adsorb the heavier VOCs, such as PCE; Carbopack B to adsorb the lighter volatiles, such as TCE; and Carbosieve S-III to adsorb the ultralight volatiles, such as vinyl chloride. A computerized mass-flow controller was used to regulate airflow and to accurately measure the volume sampled. The flow controller was typically programmed to pump 200 ml of soil gas at a flow rate of 100 ml/minute with less than 2 percent error, independent of temperature and pressure conditions. When the specified flow volume was obtained, a solenoid valve automatically closed, and the sample collection was completed.

Cartridge duplicate samples were collected consecutively. Simultaneous cartridge sampling was not possible because the mass-flow controller regulating the flow of soil gas could only be used for one cartridge at a time.



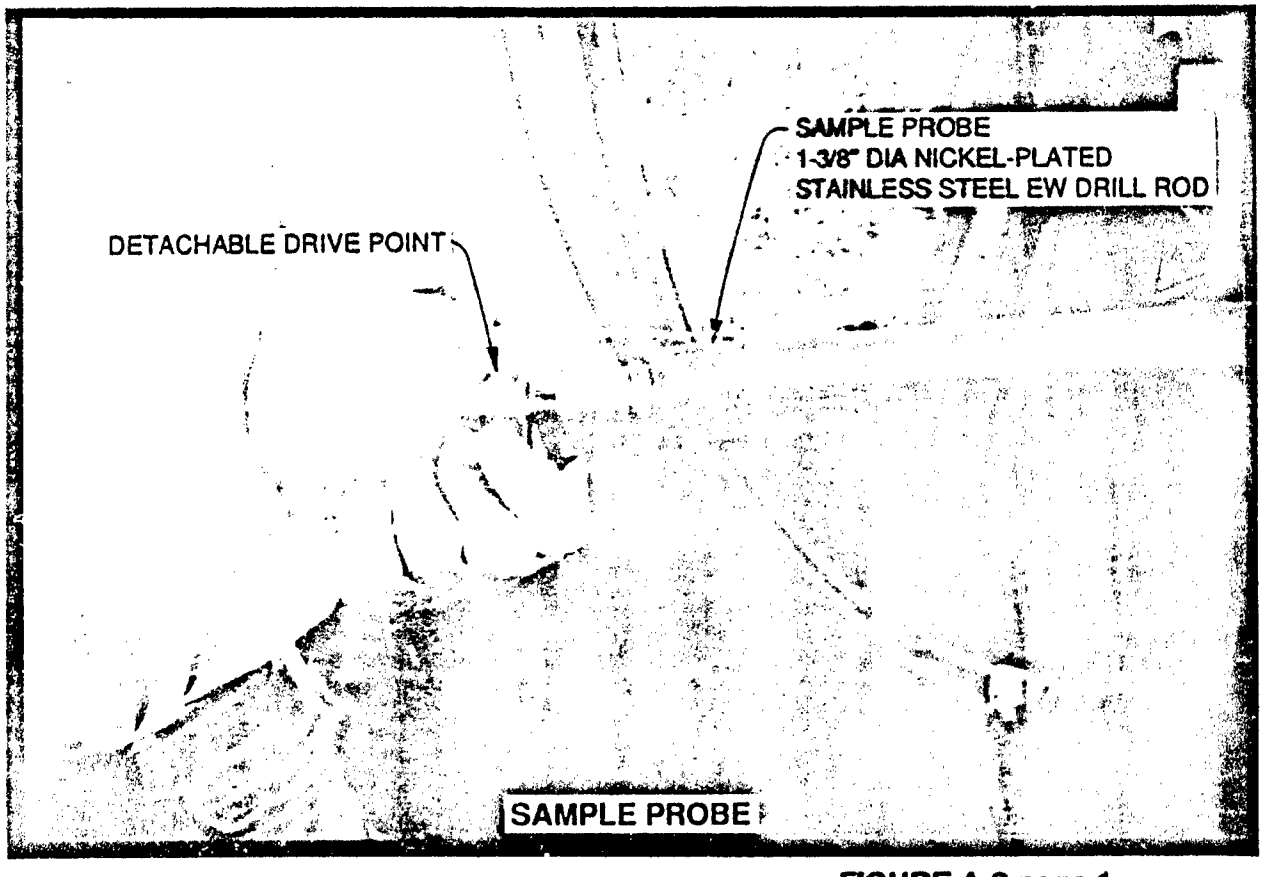


FIGURE A-2 page 1
SHALLOW SOIL GAS SURVEY
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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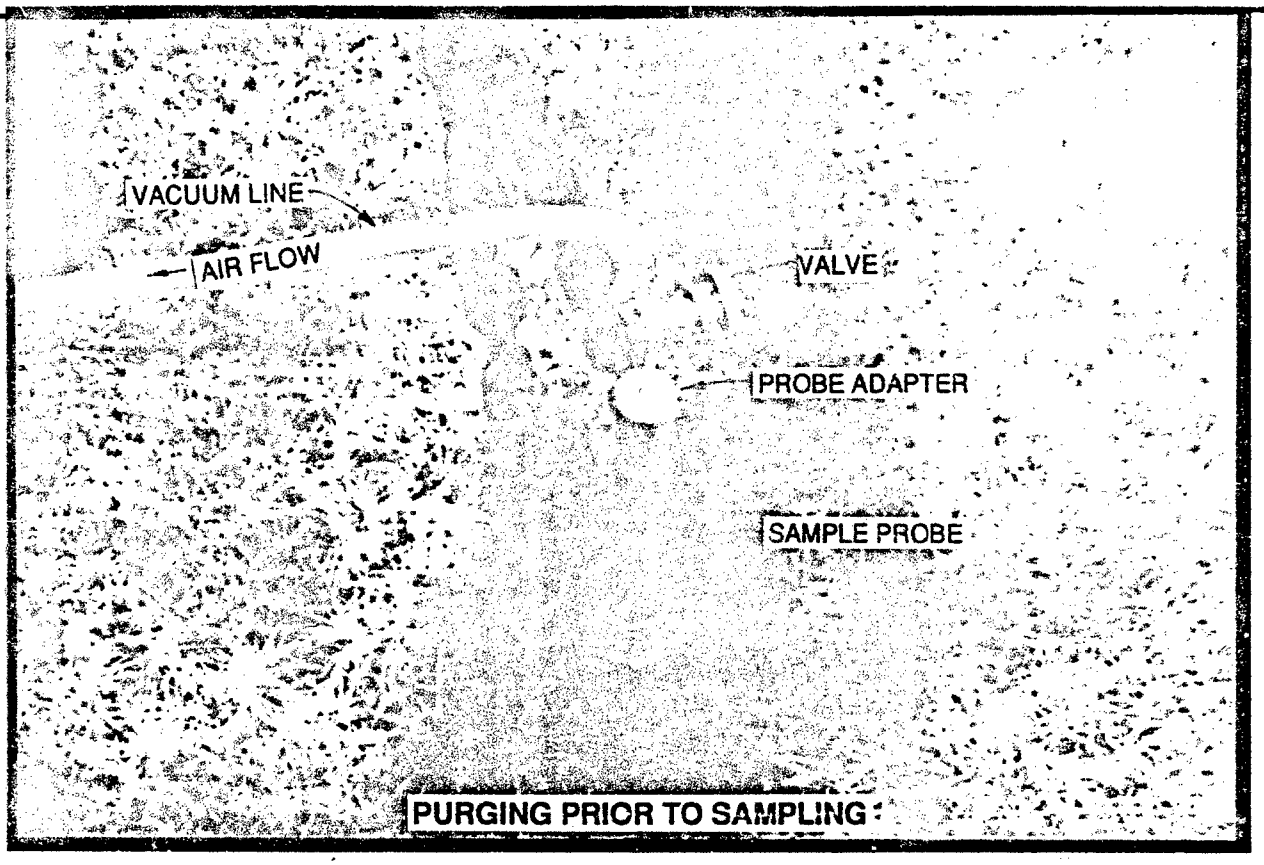

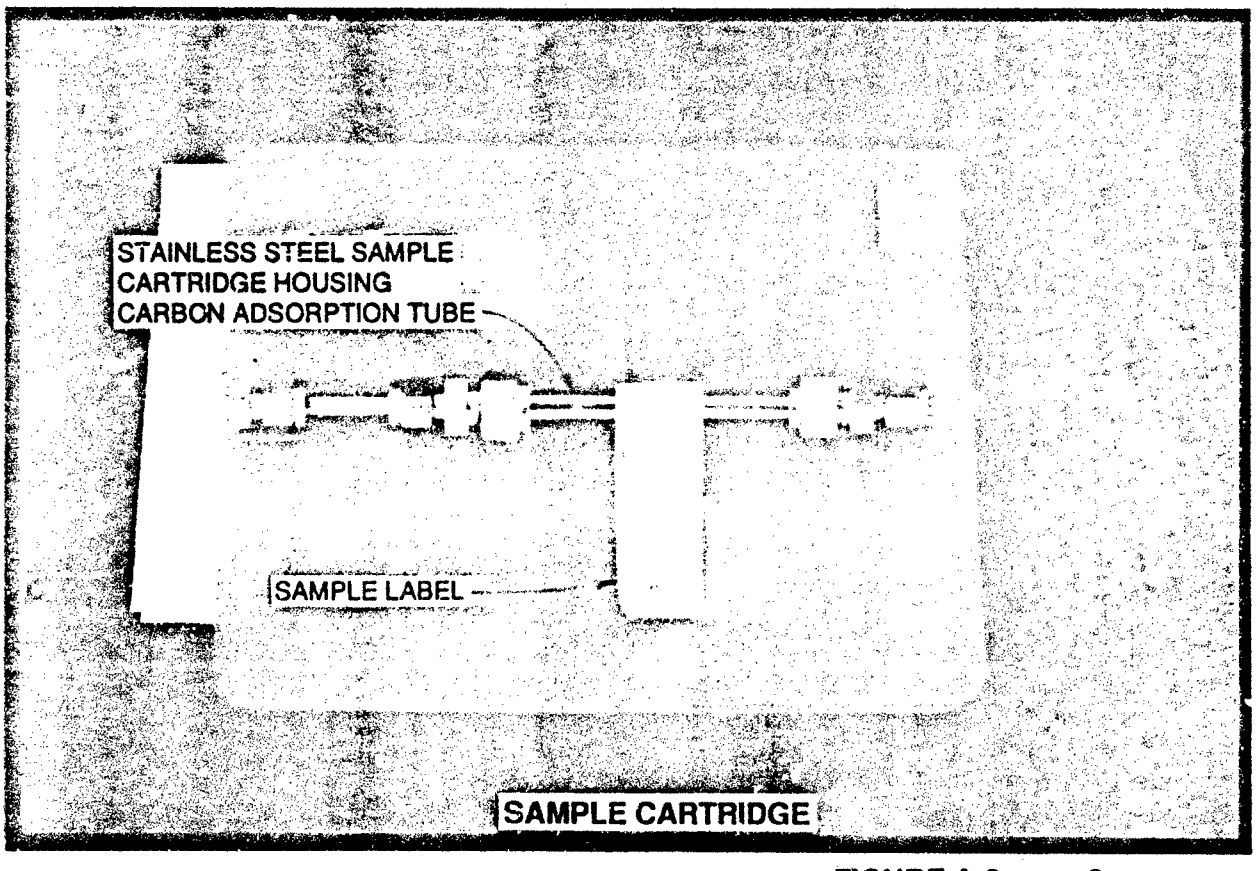

FIGURE A-2 page 2
SHALLOW SOIL GAS SURVEY
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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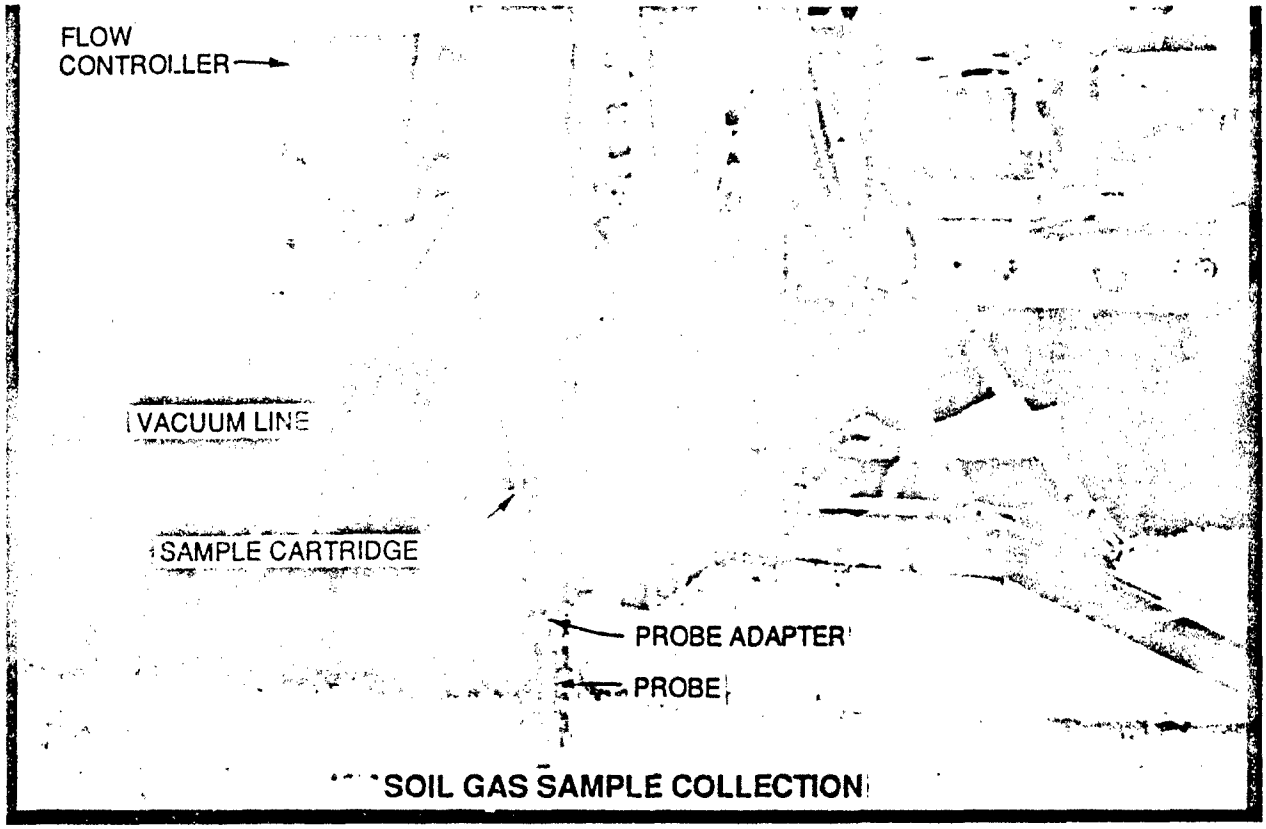

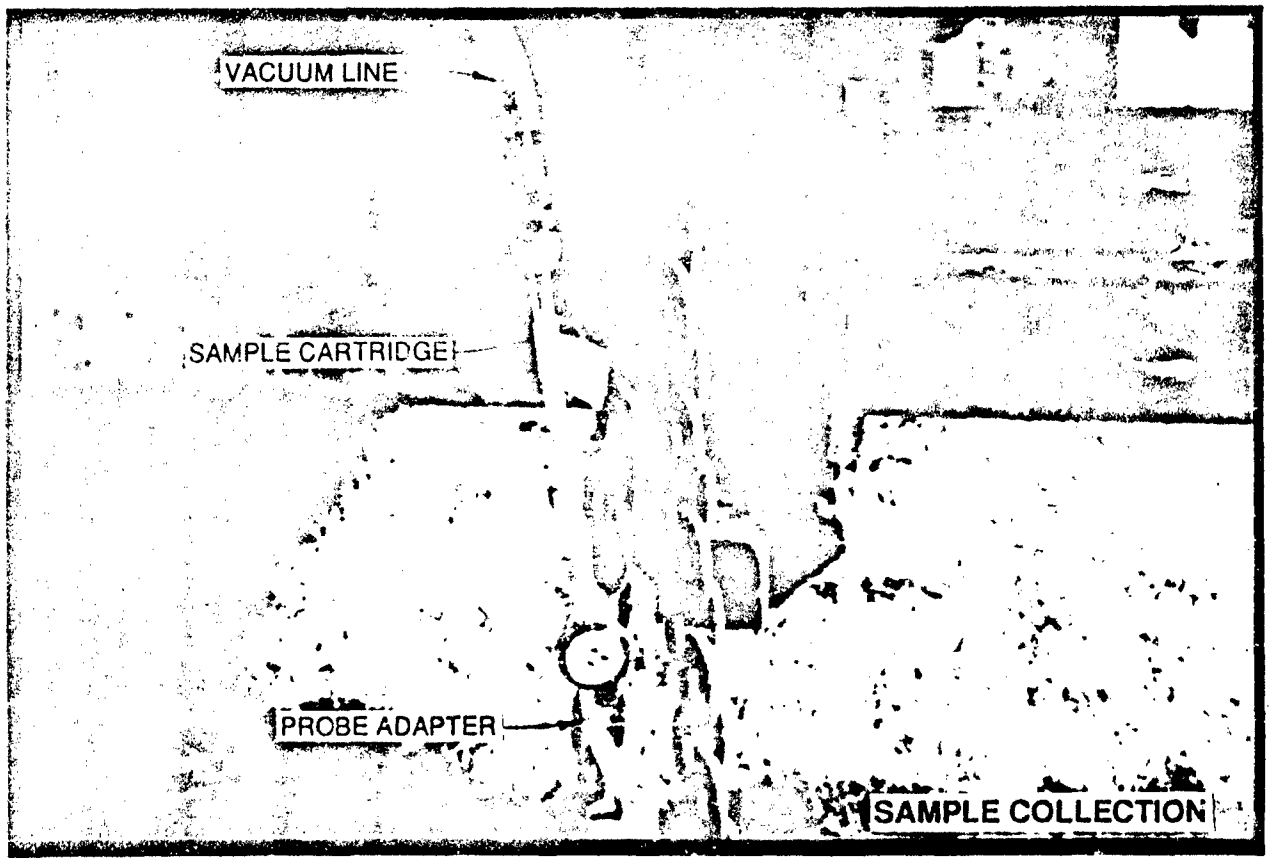

FIGURE A-2 page 3
SHALLOW SOIL GAS SURVEY
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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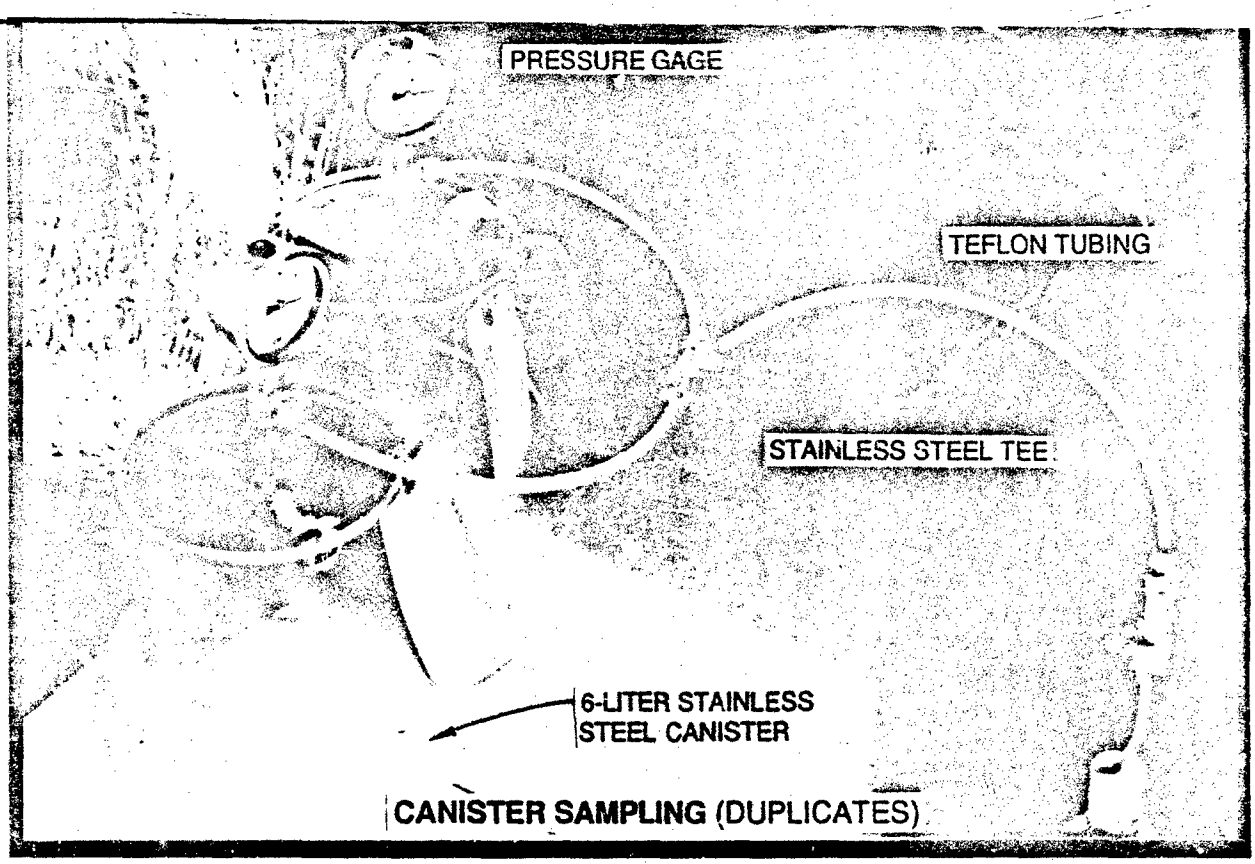

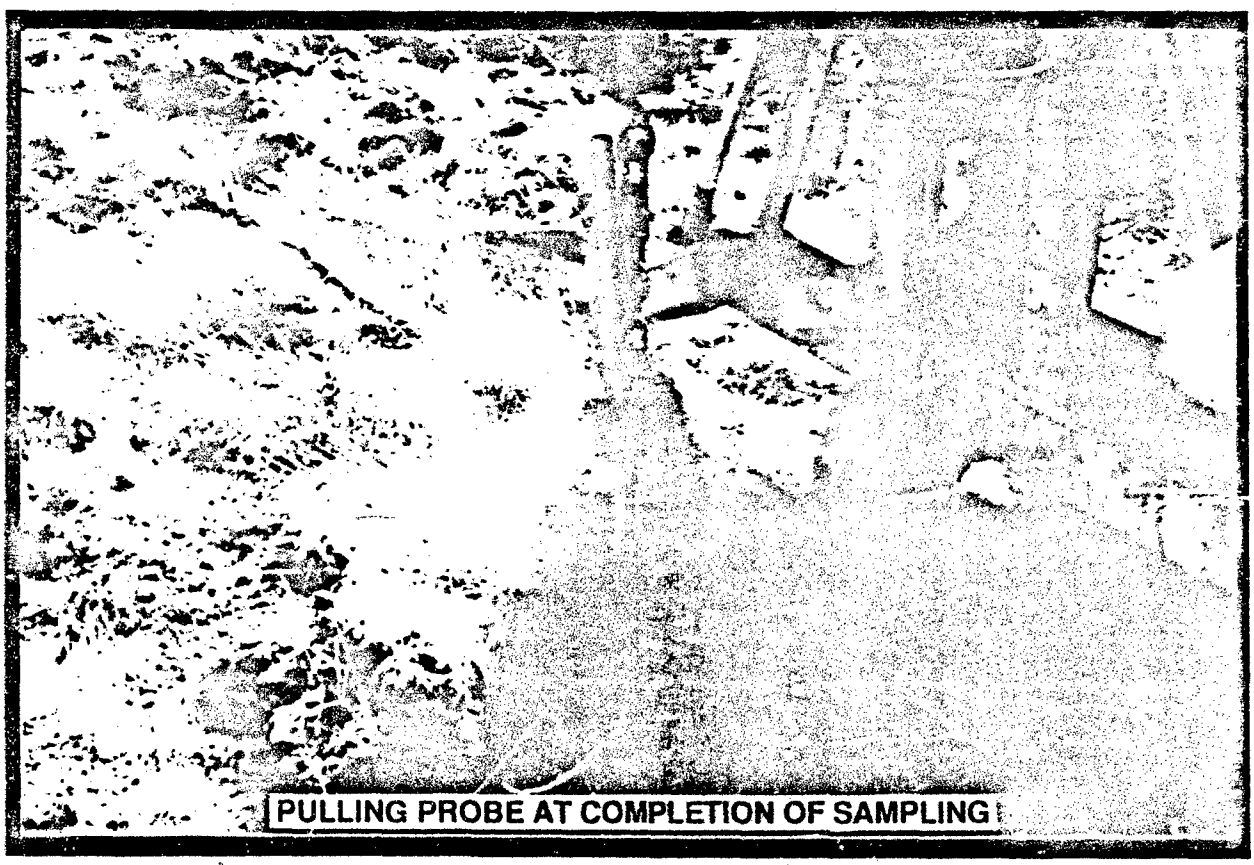

FIGURE A-2 page 4
SHALLOW SOIL GAS SURVEY
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Offsite Confirmation Analysis Samples

Samples for offsite laboratory confirmation analyses were collected in evacuated 6-liter stainless steel canisters. The canister samples were collected immediately following collection of the cartridge samples. Each canister was connected to the stainless steel adapter installed at the top of the probe. Stainless steel Swagelock connections and Teflon tubing were used to connect the canisters to the probe adapters.

After connection to the probe adapter, samples were collected by opening the adapter and canister valves and allowing the soil gas to enter the canister. All initial canister pressures were minus 30 inches of mercury or less. After sample collection, all final canister pressures were between minus 4.0 and 10.5 inches of mercury.

Canister duplicate samples were collected simultaneously by using a stainless steel tee and equal lengths of Tefion tubing connected to the probe adapter.

SVMW Sampling

Following the shallow soil gas survey, five SVMWs and nine piezometers were installed in the areas of highest soil gas contamination. Details of well construction and descriptions of the installation procedures are provided in Appendix D, Summary of Field Activity Figure A-1 shows the locations of the five SVMWs and associated piezometers (e.g., SVMW CH-1 and associated Shallow Piezometer P-1S and Deep Piezometer P-1D).

Initial sampling of the SVMWs and piezometers was conducted in December 1992. Five wells and five shallow piezometers were sampled in accordance with Section 11.0 of the Draft Final SAP (CH2M HILL, 1992). The sampled wells and piezometers included CH-1, P-1S, CH-2, P-2M, CH-3, P-3S, CH-4, P-4S, CH-5, and P-5S. Because of relatively high winter groundwater levels, the screened intervals of the four deepest piezometers (P-1D, P-3D, P-4D, and P-5D) were submerged and could not be sampled. Three deep piezometers (P-1D, P-3D, and P-4D) were sampled on August 8, 1993. P-5D was still submerged.

Prior to sampling, each well or piezometer was purged of 3 well volumes using a vacuum pump. Soil vapor samples were then collected in evacuated 6-liter stainless steel canisters. A field duplicate sample was collected from Well CH-1 using a stainless steel cross in the sampling train.

Laboratory Analyses

This section describes the analytical methodologies and summary results for dry or partially submerged groundwater monitoring samples, shallow soil gas samples and SVMW/piezometer samples. Results from the December 1992 sampling are

summarized in Tables A-8 and A-9. Results from the August 1993 sampling are summarized in Attachment A-2.

Dry Groundwater Monitoring Well Soil Vapor Samples

All of the samples collected from dry or partially submerged groundwater monitoring wells were analyzed at Air Toxics Ltd., located in Rancho Cordova, California. The samples were analyzed for soil gas VOCs in accordance with EPA Method TO-14 using a gas chromatograph/mass spectrometer (GC/MS) operating in full-scan mode.

In addition to VOC analyses, selected samples were also analyzed for oxygen, nitrogen, methane, and carbon dioxide using modified ASTM Method D3416 and a GC equipped with thermal conductivity and flame ionization detectors (GC/TCD/FID).

Tables A-3 and A-4 summarize the results of soil vapor analyses conducted on samples from groundwater monitoring wells.

Table A-3
Summary of Detected Soil Gas VOCs
Dry or Partially Submerged
Groundwater Monitoring Well Sampling[a]
August 21, 1992
(µg/l)

Compound[b]	Well and Screened Interval (feet bgs)			
	MW-1 (61 to 81)	MW-3 (61 to 81)	MW-5 (59 to 79)	MW-7 (61 to 81)
Freon-12	-[c]	0.25	-	-
Vinyl Chloride	-	-	-	-
Chloromethane	0.02	-	-	-
1,1-Dichloroethene	0.07	-	6.0	-
Freon-113	0.01	107E[d]	-	-
1,1-Dichloroethane	0.06	-	-	-
cis-1,2-Dichloroethene	0.91E	0.37	-	-
1,1,1-Trichloroethane	-	-	0.07	-
Benzene	-	0.01	-	-
Trichloroethene	1.5E	2.8	2.7	0.05
Toluene	0.31	-	0.21	0.02
Tetrachloroethene	0.56	6.4	95E	0.02

[a]Maximum detected analyte concentrations are listed where duplicate samples were analyzed.
[b]Compounds common to onsite GC analyses conducted during the RI shallow soil gas survey are bolded.
[c]Compound not detected above quantitation limit. Quantitation limits vary from sample to sample because of dilution factors.
[d]Analyte concentration exceeded calibration range, but within linear range.

Table A-4 Summary of Detected Atmospheric Gases Dry or Partially Submerged Groundwater Monitoring Well Sampling August 21, 1992 (percent)[a]		
Compound	Well and Screened Interval (feet bgs)	
	MW-1 (61 to 81)	MW-5 (59 to 79)
Oxygen	15	19
Nitrogen	59	70
Methane	0.11	-[b]
Carbon dioxide	0.94	0.93

[a]Maximum analyte concentrations are listed where field or laboratory duplicate samples were analyzed.
[b]Compound not detected above quantitation limit.

Quality Control

Quality control (QC) measures for soil gas samples collected from dry or partially submerged groundwater wells included field quality control samples and internal laboratory QC samples.

Field QC Samples. Field QC samples consisted of one field duplicate and one field blank. The samples were collected at a frequency of approximately 1 in 10. The samples were submitted "blind" to the analytical laboratory. All of the samples were received intact at the laboratory in accordance with chain-of-custody procedures.

One field duplicate for VOC analysis was collected from MW-3 and designated MW-200. A stainless steel cross in the sample tubing was used to collect the samples simultaneously. Relative percent differences (RPDs) between detected compounds ranged between 2.0 and 8.0 percent. The field duplicate RPD acceptability criterion for measurements in air is less than 50 percent (Table 4-3, IRP QAPP) (Radian, 1992). Therefore, acceptability criteria were met for all compounds.

One field blank sample, designated MW-100, was collected in a randomly selected canister using ultra-high purity air. No method analytes were detected.

Laboratory QC Samples. Internal laboratory QC samples for VOC analysis consisted of laboratory blanks, surrogate spikes, and method spikes. Laboratory QC samples for the analysis of atmospheric gases consisted of a laboratory duplicate and a laboratory blank.

Three laboratory blank samples were analyzed. No method analytes were detected in any of the samples.

Spiked analyses consisted of surrogate spikes and a method spike. Each field sample and laboratory blank sample was spiked with three surrogate compounds. The surrogate spike recovery acceptance criterion is plus or minus 30 percent (Radian, 1992). All surrogate spike recoveries were within quality control limits, except for the recovery of surrogate compound toluene-d8 in MW-1. Matrix effects in this sample resulted in a surrogate recovery of 132 percent.

All method spike compounds met QC acceptance criteria of plus or minus 30 percent.

For atmospheric gas analyses, one laboratory duplicate sample was analyzed for Sample MW-1. RPDs ranged from zero to 35 percent. Analysis of the laboratory blank sample, consisting of ultra-high purity nitrogen, detected 100 percent nitrogen and no other compound.

Shallow Soil Gas Samples

Shallow soil gas samples were analyzed at an onsite mobile laboratory and confirmation samples at an offsite laboratory. Descriptions of both types of analyses are in the following paragraphs.

Onsite Analyses

Onsite analyses were performed using gas chromatography techniques to identify and quantify target VOCs. Soil gas adsorption cartridges were desorbed using an Envirochem 890 Thermal Tube Desorber operating at 280°C. The desorbed samples were injected by the desorber into a Varian 3400 gas chromatograph equipped with a Megabore DB 624, 30m capillary column, a Tracor 703 photoionization detector (PID), and a Tracor 700A Hall detector. A split sample from the thermal desorber was sent to a DB1, 30m Megabore capillary column and a Varian flame ionization detector (FID) for second column analysis.

Target analytes for onsite GC analyses consisted of the following compounds:

- PCE
- TCE
- 1,1-DCE
- Vinyl chloride
- Benzene
- Toluene
- Ethyl benzene
- m- and p-Xylenes
- o-Xylene
- TVOCs

The detection limit for all compounds was 0.01 μg/l.

Each cartridge sample was analyzed for each of the above listed compounds. The onsite laboratory analytical data are summarized in Table A-5. Laboratory data sheets and summaries of the data on a parts per billion-volume basis are provided in Attachment A-1.

Offsite Analyses

Offsite confirmation analyses for soil gas VOCs were performed in accordance with EPA Method TO-14 using GC/MS techniques. The samples were analyzed at the Air Toxics, Ltd., laboratory located in Rancho Cordova, California. Twelve 6-liter canister confirmation samples were collected in the field. The canister samples consisted of 10 primary samples, 1 field duplicate, and 1 field blank. Table A-6 lists the canister confirmation samples that were collected.

Offsite laboratory confirmation sample data are summarized in Table A-7.

Quality Control

QC measures for shallow soil gas samples were performed for both onsite laboratory GC analyses and offsite laboratory GC/MS analyses. QC samples for onsite GC analyses included laboratory systems blanks, calibration standards, surrogate spikes, field duplicates, field blanks, and trip blanks. QC measures for offsite GC/MS confirmation samples included field blank and duplicate samples and internal laboratory QC measures, including laboratory blanks, surrogate spikes, and method spikes.

Field QC Samples. Field QC samples for onsite GC analyses of shallow soil gas samples included nine atmospheric field blanks and seven trip blanks. No chlorinated analytes (e.g., PCE) were detected in any of the field or trip blank samples. Fuel constituent aromatic compounds (i.e., benzene, toluene, ethylbenzene, and xylenes) were found at low concentrations in both field and trip blanks. Refer to Attachment A-1 for tabulations of detected compounds in the field QC samples.

Field QC samples for offsite GC/MS confirmation analyses consisted of a field duplicate and a field blank. The samples were collected a frequency of approximately 1 in 10. The samples were submitted "blind" to the analytical laboratory. All of the samples were received intact at the laboratory in accordance with chain-of-custody procedures.

One field duplicate was collected at shallow soil gas location SG30-20 and designated SG200-20. A stainless steel cross in the sample tubing was used to collect the samples simultaneously. Relative percent differences (RPDs) between detected compounds ranged between 3.6 to 200 percent. The field duplicate RPD acceptability criterion for measurements in air is less than 50 percent (Table 4-3, IRP QAPP) (Radian, 1992). Acceptability criteria were not met for 1,1-dichloroethene (159 percent), Freon-113 (200 percent), and toluene (80 percent).

Table A-5
Summary of Shallow Soil Gas Data--September 15 to October 6, 1992
Micrograms Per Liter (µg/L)
Davis Global Communications Site

Sample	Vinyl Chloride	1,1 DCE	TCE	PCE	Benzene	Toluene	Ethyl Benzene	m- & p-Xylenes	o-Xylene
SG01-10	<0.01	<0.01	<0.01	4.00	0.16	0.32	0.16	0.16	0.16
SG02-10	<0.01	<0.01	<0.01	<0.01	0.25	0.69	0.25	0.33	0.23
SG03-10	<0.01	<0.01	<0.01	<0.01	0.21	0.58	0.25	0.31	0.26
SG04-10	<0.01	<0.01	<0.01	<0.01	0.27	0.70	0.28	0.42	0.29
SG05-10	<0.01	0.27	2.70	14.00	0.13	0.12	0.14	0.15	0.17
SG05-13	<0.01	<0.01	0.05	0.30	0.10	0.15	0.05	0.20	0.10
SG06-10	<0.01	<0.01	0.44	14.00	0.16	0.19	0.17	0.26	0.24
SG07-10	<0.01	<0.01	<0.01	<0.01	0.20	0.20	0.25	0.25	0.20
SG08-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG08-10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG08-20	<0.01	<0.01	<0.01	1.45	<0.01	<0.01	<0.01	<0.01	<0.01
SG09-05	<0.01	<0.01	<0.01	11.00	<0.01	0.16	0.06	0.18	0.08
SG09-10	<0.01	0.15	0.05	41.00	<0.01	<0.01	<0.01	<0.01	<0.01
SG09-20	<0.01	0.07	0.03	26.00	<0.01	<0.01	<0.01	<0.01	<0.01
SG10-10	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	<0.01	<0.01	<0.01
SG11-05	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	<0.01	0.06	<0.01
SG11-10	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01
SG11-20	<0.01	0.32	<0.01	0.97	<0.01	0.04	<0.01	0.04	<0.01
SG12-10	<0.01	<0.01	<0.01	<0.01	0.09	0.22	<0.01	0.13	0.19
SG13-05	<0.01	0.53	4.00	77.00	<0.01	0.07	0.01	0.10	0.06
SG13-10	<0.01	<0.01	<0.01	0.08	<0.01	0.06	<0.01	0.07	<0.01
SG13-20	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	0.05	<0.01
SG14-10	<0.01	<0.01	0.04	0.06	<0.01	<0.01	<0.01	<0.01	<0.01
SG15-05	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.10	<0.01
SG15-10	<0.01	<0.01	0.61	1.90	<0.01	<0.01	<0.01	<0.01	<0.01
SG15-20	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.06	<0.01
SG16-10	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01
SG17-10	<0.01	<0.01	0.04	0.06	<0.01	<0.01	<0.01	<0.01	<0.01
SG18-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG18-10	<0.01	<0.01	0.36	11.00	<0.01	<0.01	<0.01	<0.01	<0.01
SG18-17	<0.01	<0.01	0.13	4.80	<0.01	<0.01	<0.01	<0.01	<0.01
SG19-10	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
SG20-10	<0.01	<0.01	<0.01	14.50	<0.01	<0.01	<0.01	<0.01	<0.01
SG21-10	<0.01	<0.01	0.29	0.10	<0.01	<0.01	<0.01	<0.01	<0.01
SG22-05	<0.01	<0.01	<0.01	2.04	<0.01	0.06	0.07	0.09	0.08
SG22-10	<0.01	<0.01	0.09	52.00	<0.01	<0.01	<0.01	<0.01	<0.01
SG22-20	<0.01	<0.01	<0.01	9.70	0.04	0.06	<0.01	0.05	<0.01
SG23-10	<0.01	<0.01	<0.01	0.07	<0.01	0.08	<0.01	0.08	<0.01
SG24-10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG25-10	<0.01	<0.01	<0.01	0.05	<0.01	6.80	5.80	16.30	17.50
SG26-10	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
SG27-10	<0.01	<0.01	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	<0.01
SG28-10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG29-05	<0.01	<0.01	<0.01	0.26	<0.01	<0.01	<0.01	0.06	<0.01
SG29-10	<0.01	0.34	3.80	340.00	<0.01	<0.01	<0.01	<0.01	<0.01
SG29-20	<0.01	<0.01	<0.01	0.13	0.04	0.05	<0.01	0.05	0.05
SG30-05	<0.01	<0.01	<0.01	0.22	0.26	0.57	0.13	0.39	0.17

Table A-5
Summary of Shallow Soil Gas Data--September 15 to October 6, 1992
Micrograms Per Liter (µg/L)
Davis Global Communications Site

Sample	Vinyl Chloride	1,1 DCE	TCE	PCE	Benzene	Toluene	Ethyl Benzene	m- & p- Xylenes	o- Xylene
SG30-10	<0.01	<0.01	0.71	29.00	<0.01	0.07	<0.01	<0.01	<0.01
SG30-20	<0.01	1.60	5.20	110.00	0.05	0.05	<0.01	0.05	0.05
SG31-10	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01
SG32-10	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01
SG33-10	<0.01	<0.01	<0.01	<0.01	0.06	0.14	<0.01	0.11	<0.01
SG34-10	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	<0.01
SG35-10	<0.01	<0.01	0.07	0.53	0.07	0.08	<0.01	0.05	0.07
SG36-05	<0.01	1.20	12.70	88.00	<0.01	<0.01	<0.01	0.05	<0.01
SG36-20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG37-10	<0.01	<0.01	<0.01	0.31	<0.01	<0.01	<0.01	<0.01	<0.01
SG38-10	<0.01	<0.01	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	<0.01
SG39-10	<0.01	0.84	0.05	5.02	<0.01	<0.01	<0.01	<0.01	<0.01
SG40-10	<0.01	<0.01	0.06	0.21	<0.01	<0.01	0.06	<0.01	<0.01
SG41-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG41-20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG42-20	<0.01	<0.01	<0.01	<0.01	0.05	0.11	<0.01	0.07	<0.01
SG43-10	<0.01	0.05	0.01	0.02	0.01	0.02	0.03	0.03	0.03
SG44-10	<0.01	0.12	0.01	0.04	0.05	0.11	0.19	0.21	0.22
SG45-10	<0.01	0.09	0.02	0.07	0.05	0.14	0.24	0.28	0.30
SG46-10	<0.01	0.03	0.02	0.05	0.05	0.14	0.25	0.27	0.30
RA01-05	<0.01	<0.01	<0.01	2.80	0.05	0.08	<0.01	0.11	<0.01
RA02-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
RA03-05	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
RA04-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Note:
Sample depths are coded in sample location number. Sample locations given in Figure A-1.
For example, Sample SG01-10 indicates location 01 at a depth of 10 feet bgs.
For field duplicate samples, the maximum detected analyte concentration is given (i.e., the maximum of the two values).

Table A-6 Offsite Laboratory Confirmation Analysis Samples	
SG04-10	SG22-05
SG07-10	SG30-20
SG08-05	SG34-10
SG09-10	SG41-20
SG09-20	SG100-10 (field blank)
SG19-10	SG200-20 (field duplicate of SG30-20)

Note:

1. All samples collected in evacuated 6-liter stainless steel canisters.
2. Field duplicates collected simultaneously by using stainless steel tee.
3. Field blank collected using ultra-high purity air.
4. Laboratory analysis in accordance with EPA Method TO-14 using GC/MS.

One field blank sample, designated SG100-10, was collected in a randomly selected canister using ultra-high purity air. No method analytes were detected in the sample.

Laboratory QC Samples. Onsite laboratory QC included laboratory systems blanks, calibration standards, and surrogate spikes. A systems blank and three calibration runs were performed at the beginning of each day. Additional calibrations were performed after every 10 samples. Surrogate spikes consisted of a mixture of cis- and trans-dichloropropene. Calibration curves and chromatograms are not provided with this technical memorandum. Detailed QC information is available from CH2M HILL in Redding, California.

Offsite laboratory QC samples consisted of laboratory blanks, surrogate spikes, and method spikes. Three laboratory blank samples were analyzed. No method analytes were detected in any of the samples. Spiked analyses consisted of surrogate spikes and a method spike. Each field sample and laboratory QC sample was spiked with three surrogate compounds. The surrogate spike recovery acceptance criterion is plus or minus 30 percent (Radian, 1992). All surrogate spike recoveries were within quality control limits. All method spike compounds, except trans-1,3-dichloropropene (132 percent), styrene (150 percent), and chlorotoluene (172 percent), met quality control acceptance criteria of plus or minus 30 percent. These compounds were not detected in any sample.

Table A-7
Summary of Detected VOCs
Shallow Soil Gas Offsite Confirmation Analyses[a,b]
(μg/l)

Compound[c]	SG04-10[d]	SG07-10	SG08-05	SG09-10	SG09-20	SG19-10	SG22-05	SG30-20	SG34-10	SG41-20
Vinyl Chloride	-[e]	-	-	-	-	-	-	-[e]	-	-
1,1-Dichloroethene	-	-	-	-	-	-	-	1.1E[f]	-	-
Freon-113	-	-	0.024	0.082	-	-	-	0.25	-	-
1,1,1-Trichloroethane	-	-	0.013	0.011	0.019	-	-	0.30	-	-
Benzene	0.010	0.021	0.012	-	0.013	-	-	0.014	-	0.007
Trichloroethene	-	0.11	-	0.021	0.10	-	-	2.9E	-	-
Toluene	0.037	0.063	0.035	-	0.018	-	-	0.022	0.008	0.009
Tetrachloroethene	0.86	3.0E	3.5E	19E	21E	0.20	1.1	99E	-	-
Ethylbenzene	-	0.009	0.011	-	-	-	-	-	-	-
m- & p-Xylenes	0.017	0.051	0.033	-	0.011	-	-	-	0.004	-
o-Xylene	-	0.020	0.013	-	-	-	-	-	-	-
1,3,5-Trimethylbenzene	-	0.017	0.008	-	0.008	-	-	-	-	-
1,2,4-Trimethylbenzene	0.009	0.077	0.024	-	0.012	-	-	-	-	-

[a]Samples analyzed by GC/MS in accordance with EPA Method TO-14.
[b]Maximum detected analyte concentrations are listed where field duplicate samples were analyzed.
[c]Compounds common to onsite GC analyses are bolded.
[d]Sample depths are coded in sample number. For example, SG04-10 indicates a sample collected at location 04 at a depth of 10 feet bgs.
[e]Compound not detected above quantitation limit. Quantitation limits vary from sample to sample because of dilution factors.
[f]Analyte concentration exceeded calibration range, but within linear range.

SVMW Samples

All of the SVMW canister samples were analyzed at Air Toxics, Ltd., located in Rancho Cordova, California. The samples were analyzed for soil gas VOCs in accordance with EPA Method TO-14 using a GC/MS operating in full-scan mode. To quantify low- and high-level contaminants, most of the samples were analyzed twice. Samples were initially analyzed with minimal dilution to quantify low concentration contaminants at the lowest practical quantitation limit. The samples were subsequently reanalyzed with dilution to quantify high level contaminants.

Although most samples were analyzed twice to quantify low- and high-range contaminants, some data are flagged with an "E" qualifier on the laboratory data sheets. The "E" flag indicates that a particular analyte was detected at a concentration that exceeded the instrument calibration range, but was within the linear range. The qualified data are a consequence of the wide range of target analyte concentrations. Sample dilutions were determined based on the highest concentration analytes. In diluting a sample sufficiently to quantify the highest concentration analytes, the detection limit was necessarily increased. For other analytes in the same sample, the higher detection limit was greater than the compound concentration. These compounds are therefore "Not Detected" in the diluted sample. Under this condition, the undiluted analytical results are given, some being qualified with an "E" flag.

In addition to VOC analyses, selected samples were also analyzed for oxygen, nitrogen, carbon monoxide, methane, carbon dioxide, and total nonmethane hydrocarbon content using modified ASTM Method D3416 and a GC equipped with thermal conductivity and flame ionization detectors (GC/TCD/FID).

Tables A-8 and A-9 summarize the results of the SVMW sample analyses.

Quality Control

Quality control (QC) measures for SVMW samples included field QC samples and internal laboratory QC samples. The laboratory data were reviewed to assess their acceptability, as defined by criteria given in the Installation Restoration Program (IRP) Quality Assurance Project Plan (QAPP) (Radian, 1992).

Field QC Samples. Field QC samples consisted of one field duplicate and one field blank. The samples were collected at a frequency of approximately 1 in 10. The samples were submitted "blind" to the analytical laboratory. All of the samples were received intact at the laboratory in accordance with chain-of-custody procedures.

One field duplicate was collected from CH-1 and designated CH-6. A stainless steel cross in the sample tubing was used to collect the samples simultaneously. Relative percent differences (RPDs) between detected compounds ranged between zero and 32.6 percent. The field duplicate RPD acceptability criterion for measurements in air is less than 50 percent (Table 4-3, IRP QAPP) (Radian, 1992). Therefore, acceptability criteria were met for all compounds where RPDs could be calculated.

Table A-8
Summary of Detected VOCs
December 1992 Soil Vapor Monitoring Well and Piezometer Sampling[a,b]
(μg/l)

Compound[c]	Well and Screened Interval (feet bgs)									
	CH-1 (25 to 35)	P-1S (14 to 16)	CH-2 (14 to 16)	P-2M (30 to 35)	CH-3 (22 to 32)	P-3S (15 to 17)	CH-4 (27 to 37)	P-4S (17 to 19)	CH-5 (28 to 38)	P-5S (18 to 20)
Freon-12	0.016	-	-	-	-	-	-	-	0.48	-
Vinyl Chloride	-	-	-	-	-	-	-	-	1.3	-
1,1-Dichloroethene	4.7	0.16	3.1	7.0	4.3	1.2	10	8.5	-	-
Freon-113	7.50	-	2.2	3.7	1.4	-	0.19	-	0.097	-
1,1-Dichloroethane	0.017	-	-	-	0.012	-	0.11	-	0.064	-
cis-1,2-Dichloroethene	0.074	-	0.018	-	0.054	-	1.6	1.2	0.047	-
Chloroform	0.029	-	0.016	-	-	-	0.033	-	-	-
1,1,1-Trichloroethane	1.7	-	0.80	1.9	1.4	-	0.36	-	-	-
Benzene	0.050	-	0.056	-	0.044	-	0.072	-	1.1	-
1,2-Dichloroethane	-	-	-	-	-	-	0.008	-	-	-
Trichloroethene	7.9	0.33	8.9	12	6.8	4.0	50	39	0.089	-
Toluene	0.007	26	2.9	-	0.017	-	0.28	-	-	23
Tetrachloroethene	390	17	330	340	210	90	270	200	0.60	-
Ethylbenzene	-	-	-	-	-	-	-	-	0.081	-

[a]Maximum detected analyte concentrations are listed where field or laboratory duplicate samples were analyzed.
[b]Samples analyzed by GC/MS in accordance with EPA Method TO-14.
[c]Compound not detected above quantitation limit. Quantitation limits vary from sample to sample because of dilution factors.

One field blank sample, designated CH-7, was collected in a randomly-selected canister using ultra-high purity air. Four method analytes were detected in the field blank, including: chloroform (2.4 ppbv), trichloroethene (18 ppbv), toluene (1.7 ppbv), and tetrachloroethene (20 ppbv).

Table A-9
Summary of Detected Atmospheric Gases
December 1992 Soil Vapor Monitoring Well Sampling
(percent)

Compound	CH-1	P-2M	CH-3	CH-4	CH-5
Oxygen	15	16	16	16	-
Nitrogen	82	82	83	82	88
Carbon monoxide	-[a]	-	-	-	-
Methane	-	-	-	-	1.5
Carbon dioxide	2.5	1.5	1.2	1.6	10
Total nonmethane hydrocarbons	0.012	0.011	0.004	0.004	0.091

[a]Compound not detected above quantitation limit.

Laboratory QC Samples. Internal laboratory QC samples for VOC analysis consisted of a laboratory duplicate, laboratory blanks, surrogate spikes, and method spikes. Laboratory QC for the analysis of atmosphere gases consisted of a laboratory duplicate, method spike, and a laboratory blank.

One laboratory duplicate sample was analyzed from the canister collected at CH-2. RPDs between compounds detected in both analyses ranged between 7.8 and 19.4 percent. The acceptability criterion for laboratory duplicate analyses RPDs is less than 30 percent (Radian, 1992). Therefore, acceptance criteria were met for all compounds where RPDs could be calculated.

Five laboratory blank samples were analyzed. No method analytes were detected in any of the samples.

Spiked analyses consisted of surrogate spikes and a method spike. Each field sample and laboratory QC sample was spiked with three surrogate compounds. The surrogate spike recovery acceptance criterion is plus or minus 30 percent (Radian, 1992). All surrogate spike recoveries were within quality control limits, except for the recovery of surrogate compound toluene-d8 in CH-5. Matrix effects in this sample resulted in a surrogate recovery of 59 percent.

All method spike compounds, except Freon 114 (1,2-dichloro-1,1,2,2-tetrafluoroethane) (148 percent), 1,2,4-trichlorobenzene (40 percent), and hexachlorobutadiene (40 percent), met quality control acceptance criteria of plus or

minus 30 percent. The compounds Freon 114, 1,2,4-trichlorobenzene and hexachlorobutadiene were not detected in any sample.

For atmospheric gas analyses, one laboratory duplicate sample was analyzed for Sample CH-5. RPDs ranged from zero to 6.8 percent. Analysis of the laboratory blank sample, consisting of ultra-high purity nitrogen, detected 100 percent nitrogen and no other compound.

Works Cited

CH2M HILL. 1992a. Draft Final Davis Global Communications Site Remedial Investigations Work Plan. November 2.

CH2M HILL. 1992b. Draft Final Davis Global Communications Sites Site Remedial Investigations Sampling and Analysis Plan. November 2.

International Technology Corporation. 1992. Draft Final Preliminary Groundwater Remedial Investigation Report Davis Global Communications Site McClellan Air Force Base. Volume 1.

Radian Corporation. 1992. Draft Final Quality Assurance Project Plan. Installation Restoration Program Stage 3. McClellan Air Force Base. March.

Attachment A-1

TABLE 1
SUMMARY OF ANALYTICAL RESULTS
GLOBAL COMMUNICATIONS, DAVIS, CA
CONCENTRATIONS REPORTED AS ug/L

SAMPLE	VINYL CHLORIDE	1,1 DCE	TCE	PCE	BENZENE	TOLUENE	ETHYL BENZENE	m & p XYLENE	o-XYLENE	TOTAL VOC
FB-06-OCT92	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.01	N/A
FB15SEPT92	<0.01	<0.01	<0.01	<0.01	0.24	0.23	0.25	0.29	0.25	1.50
FB16SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	6.00
FB17SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.00
FB18SEPT92	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.96
FB19SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.10
FB20SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.70
FB21SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.85
FB22SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.06	0.07	0.07	0.62
RA01-05	<0.01	<0.01	<0.01	2.80	0.05	0.08	<0.01	0.11	<0.01	5.90
RA02-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	4.50
RA03-05A	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.90
RA03-05B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.80
RA04-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.23
SG-01-10A	<0.01	<0.01	<0.01	<0.01	0.16	0.32	0.16	0.16	0.16	7.80
SG-01-10B	<0.01	<0.01	<0.01	4.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG-02-10	<0.01	<0.01	<0.01	<0.01	0.25	0.69	0.25	0.33	0.23	2.90
SG-03-10	<0.01	<0.01	<0.01	<0.01	0.21	0.58	0.25	0.31	0.26	3.10
SG-04-10	<0.01	<0.01	<0.01	<0.01	0.27	0.70	0.28	0.42	0.29	1.80
SG-05-10A	<0.01	0.27	2.40	14.00	0.13	0.12	0.14	0.15	0.17	6.70
SG-05-10B	<0.01	0.10	2.70	11.00	<0.01	0.03	<0.01	<0.01	<0.01	4.10
SG-05-13A	<0.01	<0.01	0.05	0.15	0.10	0.15	0.05	0.20	0.10	2.20
SG-05-13B	<0.01	<0.01	0.03	0.30	<0.01	0.12	<0.01	0.12	0.07	4.70
SG-06-10	<0.01	<0.01	0.44	14.00	0.16	0.19	0.17	0.26	0.24	7.20
SG-07-10	<0.01	<0.01	<0.01	<0.01	0.20	0.20	0.25	0.25	0.20	1.80

* = Off scale see duplicate

TABLE 1
SUMMARY OF ANALYTICAL RESULTS
GLOBAL COMMUNICATIONS, DAVIS, CA
CONCENTRATIONS REPORTED AS ug/L

SAMPLE	VINYL CHLORIDE	1,1 DCE	TCE	PCE	BENZENE	TOLUENE	ETHYL BENZENE	m & p XYLENE	o-XYLENE	TOTAL VOC
SG-08-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.65
SG-08-10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.16
SG-08-20A	<0.01	<0.01	<0.01	1.30	<0.01	<0.01	<0.01	<0.01	<0.01	0.51
SG-08-20B	<0.01	<0.01	<0.01	1.45	<0.01	<0.01	<0.01	<0.01	<0.01	0.53
SG-09-05	<0.01	<0.01	<0.01	11.00	<0.01	0.16	0.06	0.18	0.08	5.10
SG-09-10	<0.01	0.15	0.05	41.00	<0.01	<0.01	<0.01	<0.01	<0.01	14.00
SG-09-20	<0.01	0.07	0.03	26.00	<0.01	<0.01	<0.01	<0.01	<0.01	7.50
SG-10-10	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	1.40
SG-11-05	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	<0.01	0.06	<0.01	0.31
SG-11-10	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	6.30
SG-11-20A	<0.01	0.32	<0.01	0.87	<0.01	0.04	<0.01	0.04	<0.01	2.50
SG-11-20B	<0.01	0.32	<0.01	0.97	<0.01	<0.01	<0.01	<0.01	<0.01	0.90
SG-12-10	<0.01	<0.01	<0.01	<0.01	0.09	0.22	<0.01	0.13	0.19	3.40
SG-13-05A	<0.01	0.53	4.00	34.00*	<0.01	0.07	<0.01	0.10	0.06	22.40
SG-13-05B	<0.01	0.26	3.93	77.00	<0.01	0.02	0.01	0.04	0.02	24.30
SG-13-10	<0.01	<0.01	<0.01	0.08	<0.01	0.06	<0.01	0.07	<0.01	4.70
SG-13-20A	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	1.60
SG-13-20B	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	0.62
SG-14-10	<0.01	<0.01	0.04	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	1.60
SG-15-05	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.10	<0.01	0.63
SG-15-10	<0.01	<0.01	0.61	1.90	<0.01	<0.01	<0.01	<0.01	<0.01	2.50
SG-15-20A	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.06	<0.01	0.70
SG-15-20B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.50
SG-16-10A	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	2.90
SG-16-10B	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	1.70

* = Off scale see duplicate

TABLE 1
SUMMARY OF ANALYTICAL RESULTS
GLOBAL COMMUNICATIONS, DAVIS, CA
CONCENTRATIONS REPORTED AS ug/L

SAMPLE	VINYL CHLORIDE	1,1 DCE	TCE	PCE	BENZENE	TOLUENE	ETHYL BENZENE	m & p XYLENE	o-XYLENE	TOTAL VOC
SG-17-10	<0.01	<0.01	0.04	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.71
SG-18-05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.74
SG-18-10	<0.01	<0.01	0.36	11.00	<0.01	<0.01	<0.01	<0.01	<0.01	3.00
SG-18-17	<0.01	<0.01	0.13	4.80	<0.01	<0.01	<0.01	<0.01	<0.01	2.00
SG-19-10A	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	1.80
SG-19-10B	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	0.58
SG-20-10	<0.01	<0.01	<0.01	14.50	<0.01	<0.01	<0.01	<0.01	<0.01	5.70
SG-21-10	<0.01	<0.01	0.29	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	1.10
SG-22-05	<0.01	<0.01	<0.01	2.04	<0.01	0.06	0.07	0.09	0.08	3.42
SG-22-10A	<0.01	<0.01	0.09	38.00*	<0.01	<0.01	<0.01	<0.01	<0.01	16.00
SG-22-10B	<0.01	<0.01	<0.01	52.00	<0.01	<0.01	<0.01	<0.01	<0.01	48.00
SG-22-20A	<0.01	<0.01	<0.01	6.90	<0.01	0.05	<0.01	0.05	<0.01	2.80
SG-22-20B	<0.01	<0.01	<0.01	9.70	0.04	0.06	<0.01	0.04	<0.01	3.30
SG-23-10	<0.01	<0.01	<0.01	0.07	<0.01	0.08	<0.01	0.08	<0.01	1.30
SG-24-10A	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.68
SG-24-10B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.50
SG-25-10	<0.01	<0.01	<0.01	0.05	<0.01	6.80	5.80	16.30	17.50	960.00
SG-26-10	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	1.60
SG-27-10	<0.01	<0.01	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	<0.01	0.39
SG-28-10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.60
SG-29-05	<0.01	<0.01	<0.01	0.26	<0.01	<0.01	<0.01	0.06	<0.01	0.83
SG-29-10	<0.01	0.34	3.80	340.00	<0.01	<0.01	<0.01	<0.01	<0.01	89.00
SG-29-20A	<0.01	<0.01	<0.01	0.13	0.04	0.05	<0.01	0.04	<0.01	0.73
SG-29-20B	<0.01	<0.01	<0.01	0.03	0.04	0.05	<0.01	0.05	0.05	0.92
SG-30-05	<0.01	<0.01	<0.01	0.22	0.26	0.57	0.13	0.39	0.17	4.50

* = Off scale see duplicate

TABLE 1
SUMMARY OF ANALYTICAL RESULTS
GLOBAL COMMUNICATIONS, DAVIS, CA
CONCENTRATIONS REPORTED AS ug/L

SAMPLE	VINYL CHLORIDE	1,1 DCE	TCE	PCE	BENZENE	TOLUENE	ETHYL BENZENE	m & p XYLENE	o-XYLENE	TOTAL VOC
SG-30-10	<0.01	<0.01	0.71	29.00	<0.01	0.07	<0.01	<0.01	<0.01	10.00
SG-30-20A	<0.01	1.60	5.20	146*	0.05	0.05	<0.01	0.05	0.05	38.00
SG-30-20B	<0.01	1.40	4.90	110.00	0.04	0.04	<0.01	<0.01	<0.01	36.00
SG-31-10	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.59
SG-32-10	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	2.00
SG-33-10	<0.01	<0.01	<0.01	<0.01	0.06	0.14	<0.01	0.11	<0.01	0.92
SG-34-10	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	<0.01	2.30
SG-35-10A	<0.01	<0.01	0.05	0.52	0.06	0.07	<0.01	0.05	<0.01	3.40
SG-35-10B	<0.01	<0.01	0.07	0.53	0.07	0.08	<0.01	0.05	0.07	3.90
SG-36-05A	<0.01	1.08	11.17	32.00*	<0.01	<0.01	<0.01	0.05	<0.01	26.60
SG-36-05B	<0.01	1.20	12.70	88.00	<0.01	<0.01	<0.01	<0.01	<0.01	26.10
SG-36-20A	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.64
SG-36-20B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.89
SG-37-10	<0.01	<0.01	<0.01	0.31	<0.01	<0.01	<0.01	<0.01	<0.01	0.91
SG-38-10	<0.01	<0.01	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	<0.01	0.83
SG-39-10A	<0.01	0.71	0.04	3.90*	<0.01	<0.01	<0.01	<0.01	<0.01	2.67
SG-39-10B	<0.01	0.84	0.05	5.02	<0.01	<0.01	<0.01	<0.01	<0.01	9.19
SG-40-10A	<0.01	<0.01	0.05	0.21	<0.01	<0.01	0.06	<0.01	<0.01	1.22
SG-40-10B	<0.01	<0.01	0.06	0.20	<0.01	<0.01	<0.01	<0.01	<0.01	0.87
SG-41-20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.58
SG-41-5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SG-42-20A	<0.01	<0.01	<0.01	<0.01	0.05	0.11	<0.01	0.07	<0.01	0.68
SG-42-20B	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	<0.01	0.07	<0.01	1.00
SG-43-10	<0.01	0.05	0.01	0.02	0.01	0.02	0.03	0.03	0.03	0.87
SG-44-10	<0.01	0.12	0.01	0.04	0.05	0.11	0.19	0.21	0.22	4.70

* = Off scale see duplicate

TABLE 1
SUMMARY OF ANALYTICAL RESULTS
GLOBAL COMMUNICATIONS, DAVIS, CA
CONCENTRATIONS REPORTED AS ug/L

SAMPLE	VINYL CHLORIDE	1,1 DCE	TCE	PCE	BENZENE	TOLUENE	ETHYL BENZENE	m & p XYLENE	o-XYLENE	TOTAL VOC
SG-45-10	<0.01	0.09	0.02	0.07	0.05	0.14	0.24	0.28	0.30	4.00
SG-46-10	<0.01	0.03	0.02	0.05	0.05	0.14	0.25	0.27	0.3	2.90
TB-22-SEPT9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.85
TB15SEPT92	<0.01	<0.01	<0.01	<0.01	0.03	0.04	0.04	0.04	0.04	0.40
TB16SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.21
TB17SEPT	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TB19SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TB20SEPT92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.60
TB21SEPT	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.26

* = Off scale see duplicate

Table 2
Summary of Shallow Soil Gas Data
September 15 to October 6, 1992
(parts per billion-volume)

Sample	Vinyl Chloride	1,1 DCE	TCE	PCE	Benzene	Toluene	Ethyl Benzene	m- & p- Xylenes	o- Xylene
SG01-10	<3.9	<2.5	<1.9	590	50	85	37	37	37
SG02-10	<3.9	<2.5	<1.9	<1.5	78	183	58	76	53
SG03-10	<3.9	<2.5	<1.9	<1.5	66	154	58	71	60
SG04-10	<3.9	<2.5	<1.9	<1.5	85	186	64	97	67
SG05-10	<3.9	68	503	2064	41	32	32	35	39
SG05-13	<3.9	<2.5	9	44	31	40	12	46	23
SG06-10	<3.9	<2.5	82	2064	50	50	39	60	55
SG07-10	<3.9	<2.5	<1.9	<1.5	63	53	58	58	46
SG08-05	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG08-10	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG08-20	<3.9	<2.5	<1.9	214	<3.1	<2.7	<2.3	<2.3	<2.3
SG09-05	<3.9	<2.5	<1.9	1622	<3.1	42	14	41	18
SG09-10	<3.9	38	9	6045	<3.1	<2.7	<2.3	<2.3	<2.3
SG09-20	<3.9	18	6	3833	<3.1	<2.7	<2.3	<2.3	<2.3
SG10-10	<3.9	<2.5	<1.9	13	<3.1	<2.7	<2.3	<2.3	<2.3
SG11-05	<3.9	<2.5	<1.9	<1.5	<3.1	24	<2.3	14	<2.3
SG11-10	<3.9	<2.5	<1.9	9	<3.1	<2.7	<2.3	<2.3	<2.3
SG11-20	<3.9	81	<1.9	143	<3.1	11	<2.3	9	<2.3
SG12-10	<3.9	<2.5	<1.9	<1.5	28	58	<2.3	30	44
SG13-05	<3.9	134	745	11353	<3.1	19	2	23	14
SG13-10	<3.9	<2.5	<1.9	12	<3.1	16	<2.3	16	<2.3
SG13-20	<3.9	<2.5	<1.9	<1.5	<3.1	11	<2.3	12	<2.3
SG14-10	<3.9	<2.5	7	9	<3.1	<2.7	<2.3	<2.3	<2.3
SG15-05	<3.9	<2.5	<1.9	<1.5	<3.1	19	<2.3	23	<2.3
SG15-10	<3.9	<2.5	114	280	<3.1	<2.7	<2.3	<2.3	<2.3
SG15-20	<3.9	<2.5	<1.9	<1.5	<3.1	19	<2.3	14.	<2.3
SG16-10	<3.9	<2.5	<1.9	9	<3.1	<2.7	<2.3	<2.3	<2.3
SG17-10	<3.9	<2.5	7	9	<3.1	<2.7	<2.3	<2.3	<2.3
SG18-05	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG18-10	<3.9	<2.5	67	1622	<3.1	<2.7	<2.3	<2.3	<2.3
SG18-17	<3.9	<2.5	24	708	<3.1	<2.7	<2.3	<2.3	<2.3
SG19-10	<3.9	<2.5	<1.9	4	<3.1	<2.7	<2.3	<2.3	<2.3
SG20-10	<3.9	<2.5	<1.9	2138	<3.1	<2.7	<2.3	<2.3	<2.3
SG21-10	<3.9	<2.5	54	15	<3.1	<2.7	<2.3	<2.3	<2.3
SG22-05	<3.9	<2.5	<1.9	301	<3.1	16	16	20	18
SG22-10	<3.9	<2.5	17	7667	<3.1	<2.7	<2.3	<2.3	<2.3
SG22-20	<3.9	<2.5	<1.9	1430	13	16	<2.3	12	<2.3
SG23-10	<3.9	<2.5	<1.9	10	<3.1	21	<2.3	18	<2.3
SG24-10	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG25-10	<3.9	<2.5	<1.9	7	<3.1	1804	1336	3754	4030
SG26-10	<3.9	<2.5	<1.9	3	<3.1	<2.7	<2.3	<2.3	<2.3
SG27-10	<3.9	<2.5	<1.9	52	<3.1	<2.7	<2.3	<2.3	<2.3
SG28-10	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG29-05	<3.9	<2.5	<1.9	38	<3.1	<2.7	<2.3	13	<2.3
SG29-10	<3.9	86	708	50130	<3.1	<2.7	<2.3	<2.3	<2.3
SG29-20	<3.9	<2.5	<1.9	19	13	13	<2.3	12	12
SG30-05	<3.9	<2.5	<1.9	32	81	151	30	90	39

Table 2
Summary of Shallow Soil Gas Data
September 15 to October 6, 1992
(parts per billion-volume)

Sample	Vinyl Chloride	1,1 DCE	TCE	PCE	Benzene	Toluene	Ethyl Benzene	m- & p- Xylenes	o- Xylene
SG30-10	<3.9	<2.5	132	4276	<3.1	19	<2.3	<2.3	<2.3
SG30-20	<3.9	404	968	16218	16	13	<2.3	12	12
SG31-10	<3.9	<2.5	<1.9	9	<3.1	<2.7	<2.3	<2.3	<2.3
SG32-10	<3.9	<2.5	<1.9	6	<3.1	<2.7	<2.3	<2.3	<2.3
SG33-10	<3.9	<2.5	<1.9	<1.5	19	37	<2.3	25	<2.3
SG34-10	<3.9	<2.5	<1.9	<1.5	<3.1	19	<2.3	<2.3	<2.3
SG35-10	<3.9	<2.5	13	78	22	21	<2.3	12	16
SG36-05	<3.9	303	2365	12975	<3.1	<2.7	<2.3	12	<2.3
SG36-20	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG37-10	<3.9	<2.5	<1.9	46	<3.1	<2.7	<2.3	<2.3	<2.3
SG38-10	<3.9	<2.5	<1.9	52	<3.1	<2.7	<2.3	<2.3	<2.3
SG39-10	<3.9	212	9	740	<3.1	<2.7	<2.3	<2.3	<2.3
SG40-10	<3.9	<2.5	11	31	<3.1	<2.7	15	<2.3	<2.3
SG41-05	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG41-20	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
SG42-20	<3.9	<2.5	<1.9	<1.5	16	29	<2.3	16	<2.3
SG43-10	<3.9	13	2	3	3	5	7	7	7
SG44-10	<3.9	30	2	6	16	29	44	48	51
SG45-10	<3.9	23	4	10	16	37	55	64	69
SG46-10	<3.9	8	4	7	16	37	58	62	69
RA01-05	<3.9	<2.5	<1.9	413	16	21	<2.3	25	<2.3
RA02-05	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
RA03-05	<3.9	5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3
RA04-05	<3.9	<2.5	<1.9	<1.5	<3.1	<2.7	<2.3	<2.3	<2.3

Note:
Sample depths are coded in sample location number. For example, Sample SG01-10 indicates location 01 at a depth of 10 feet bgs.
For field duplicate samples, the maximum detected analyte concentration is given (i.e., the maximum of the two values).

Attachment A-2

9308055 CH2MHILL

RECEIVED
SEP 2 1993
CH2M HILL
REDDING

AIR TOXICS LTD.

AN ENVIRONMENTAL ANALYTICAL LABORATORY

WORK ORDER #: 9308055

Work Order Summary

CLIENT: Mr. Loren Krook
CH2MHill
2525 Airpark Drive
Redding, CA 95001

BILL TO: Same

PHONE: 916-243-5831
FAX: 916-243-1654
DATE RECEIVED: 8/9/93
DATE COMPLETED: 8/30/93

INVOICE # 1593
P.O. #
PROJECT # SAC28722.55.10
AMOUNT$: $1,475.00

FRACTION #	NAME	TEST	RECEIPT VAC./PRES.	PRICE
01A	P-3D	TO-14	13.5 "Hg	$235.00
02A	P-1D FIELD DUPLICATES	TO-14	9.5 "Hg	$235.00
03A	P-33D	TO-14	13.5 "Hg	$235.00
04A	P-4D	TO-14	10.5 "Hg	$235.00
05A	CH-10 FIELD BLANK	TO-14	5.0 "Hg	$235.00
06A	Method Spike	TO-14	NA	NC
07A	Lab Blank	TO-14	NA	NC
07B	Lab Blank	TO-14	NA	NC
07C	Lab Blank	TO-14	NA	NC

Misc. Charges	6 Liter SUMMA Canister Preparation (5) @ $50.00 each.	$250.00
	Flow Controller Preparation (1) @ $50.00 each.	$50.00

LAB NARRATIVE:
Sample [illegible] as concentrated as possible in order to produce low MDL's.
Some [illegible] are qualified as a result.
E = [illegible] calibration range, but within linear range.
Q = Exceeds Quality Control limits of 70% to 130%.

CERTIFIED BY: Linda J. Freeman
Laboratory Director

DATE: 8/30/93

180 BLUE RAVINE ROAD, SUITE B • FOLSOM, CA 95630
(916) 985-1000 • FAX (916) 985-1020

AIR TOXICS LTD.

SAMPLE NAME: P-3D
ID#: 9308055-01A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	5081606	**Date of Collection:**	8/5/93
Dil. Factor:	12	**Date of Analysis:**	8/16/93

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	6.0	0.029	Not Detected	Not Detected
Freon 114	6.0	0.041	Not Detected	Not Detected
Chloromethane	6.0	0.012	Not Detected	Not Detected
Vinyl Chloride	6.0	0.015	Not Detected	Not Detected
Bromomethane	6.0	0.023	Not Detected	Not Detected
Chloroethane	6.0	0.015	Not Detected	Not Detected
Freon 11	6.0	0.033	Not Detected	Not Detected
1,1-Dichloroethene	6.0	0.023	2900 E	11 E
Freon 113	6.0	0.045	340	2.5
Methylene Chloride	6.0	0.020	Not Detected	Not Detected
1,1-Dichloroethane	6.0	0.024	Not Detected	Not Detected
cis-1,2-Dichloroethene	6.0	0.023	16	0.062
Chloroform	6.0	0.029	Not Detected	Not Detected
1,1,1-Trichloroetnane	6.0	0.032	120	0.64
Carbon Tetrachloride	6.0	0.032	Not Detected	Not Detected
Benzene	6.0	0.019	15	0.047
1,2-Dichloroethane	6.0	0.024	Not Detected	Not Detected
Trichloroethene	6.0	0.031	2000 E	10 E
1,2-Dichloropropane	6.0	0.027	Not Detected	Not Detected
cis-1,3-Dichloropropene	6.0	0.027	Not Detected	Not Detected
Toluene	6.0	0.022	390	1.4
trans-1,3-Dichloropropene	6.0	0.027	Not Detected	Not Detected
1,1,2-Trichloroethane	6.0	0.032	Not Detected	Not Detected
Tetrachloroethene	6.0	0.040	44000 E	290 E
Ethylene Dibromide	6.0	0.045	Not Detected	Not Detected
Chlorobenzene	6.0	0.027	Not Detected	Not Detected
Ethyl Benzene	6.0	0.025	Not Detected	Not Detected
m,p-Xylene	6.0	0.025	Not Detected	Not Detected
o-Xylene	6.0	0.025	Not Detected	Not Detected
Styrene	6.0	0.025	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	6.0	0.040	Not Detected	Not Detected
1,3,5-Trimethylbenzene	6.0	0.029	Not Detected	Not Detected
1,2,4-Trimethylbenzene	6.0	0.029	Not Detected	Not Detected
1,3-Dichlorobenzene	6.0	0.035	Not Detected	Not Detected
1,4-Dichlorobenzene	6.0	0.035	Not Detected	Not Detected
Chlorotoluene	6.0	0.030	Not Detected	Not Detected
1,2-Dichlorobenzene	6.0	0.035	Not Detected	Not Detected
1,2,4-Trichlorobenzene	6.0	0.043	Not Detected	Not Detected
Hexachlorobutadiene	6.0	0.062	Not Detected	Not Detected

E = Exceeds instrument calibration range, but within linear range.

Container Type: 6 Liter SUMMA Canister

Surrogates	% Recovery	Method Limits
Octafluorotoluene	100	70-130
Toluene-d8	106	70-130
4-Bromofluorobenzene	90	70-130

AIR TOXICS LTD.

SAMPLE NAME: P-1D
ID#: 9308055-02A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	5081704	**Date of Collection:**	8/5/93
Dil. Factor:	16	**Date of Analysis:**	8/17/93

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	8.0	0.039	Not Detected	Not Detected
Freon 114	8.0	0.055	Not Detected	Not Detected
Chloromethane	8.0	0.016	Not Detected	Not Detected
Vinyl Chloride	8.0	0.020	20	0.050
Bromomethane	8.0	0.030	Not Detected	Not Detected
Chloroethane	8.0	0.021	Not Detected	Not Detected
Freon 11	8.0	0.044	Not Detected	Not Detected
1,1-Dichloroethene	8.0	0.031	5800 E	22 E
Freon 113	8.0	0.060	2400 E	18 E
Methylene Chloride	8.0	0.027	Not Detected	Not Detected
1,1-Dichloroethane	8.0	0.032	Not Detected	Not Detected
cis-1,2-Dichloroethene	8.0	0.031	64	0.25
Chloroform	8.0	0.038	8.0	0.038
1,1,1-Trichloroethane	8.0	0.043	130	0.69
Carbon Tetrachloride	8.0	0.043	Not Detected	Not Detected
Benzene	8.0	0.025	37	0.12
1,2-Dichloroethane	8.0	0.032	Not Detected	Not Detected
Trichloroethene	8.0	0.042	3200 E	17 E
1,2-Dichloropropane	8.0	0.036	Not Detected	Not Detected
cis-1,3-Dichloropropene	8.0	0.035	Not Detected	Not Detected
Toluene	8.0	0.029	35	0.13
trans-1,3-Dichloropropene	8.0	0.035	Not Detected	Not Detected
1,1,2-Trichloroethane	8.0	0.043	Not Detected	Not Detected
Tetrachloroethene	8.0	0.053	98000 E	650 E
Ethylene Dibromide	8.0	0.060	Not Detected	Not Detected
Chlorobenzene	8.0	0.036	Not Detected	Not Detected
Ethyl Benzene	8.0	0.034	Not Detected	Not Detected
m,p-Xylene	8.0	0.034	Not Detected	Not Detected
o-Xylene	8.0	0.034	Not Detected	Not Detected
Styrene	8.0	0.033	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	8.0	0.054	Not Detected	Not Detected
1,3,5-Trimethylbenzene	8.0	0.038	Not Detected	Not Detected
1,2,4-Trimethylbenzene	8.0	0.038	Not Detected	Not Detected
1,3-Dichlorobenzene	8.0	0.047	Not Detected	Not Detected
1,4-Dichlorobenzene	8.0	0.047	Not Detected	Not Detected
Chlorotoluene	8.0	0.040	Not Detected	Not Detected
1,2-Dichlorobenzene	8.0	0.047	Not Detected	Not Detected
1,2,4-Trichlorobenzene	8.0	0.058	Not Detected	Not Detected
Hexachlorobutadiene	8.0	0.083	Not Detected	Not Detected

E = Exceeds instrument calibration range, but within linear range.

Container Type: 6 Liter SUMMA Canister

Surrogates	% Recovery	Method Limits
Octafluorotoluene	103	70-130
Toluene-d8	103	70-130
4-Bromofluorobenzene	91	70-130

AIR TOXICS LTD.

SAMPLE NAME: P-33D
ID#: 9308055-03A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	**5081705 / 5081707**	**Date of Collection:**	**8/5/93**
Dil. Factor:	**6.6 / 610**	**Date of Analysis:**	**8/17/93**

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	3.3	0.016	Not Detected	Not Detected
Freon 114	3.3	0.023	Not Detected	Not Detected
Chloromethane	3.3	0.007	Not Detected	Not Detected
Vinyl Chloride	3.3	0.008	Not Detected	Not Detected
Bromomethane	3.3	0.013	Not Detected	Not Detected
Chloroethane	3.3	0.009	Not Detected	Not Detected
Freon 11	3.3	0.018	Not Detected	Not Detected
1,1-Dichloroethene	3.3	0.013	2600 E	10 E
Freon 113	3.3	0.025	320	2.4
Methylene Chloride	3.3	0.011	Not Detected	Not Detected
1,1-Dichloroethane	3.3	0.013	3.6	0.014
cis-1,2-Dichloroethene	3.3	0.013	18	0.070
Chloroform	3.3	0.016	Not Detected	Not Detected
1,1,1-Trichloroethane	3.3	0.018	110	0.59
Carbon Tetrachloride	3.3	0.018	Not Detected	Not Detected
Benzene	3.3	0.010	12	0.037
1,2-Dichloroethane	3.3	0.013	Not Detected	Not Detected
Trichloroethene	3.3	0.017	1900 E	10 E
1,2-Dichloropropane	3.3	0.015	Not Detected	Not Detected
cis-1,3-Dichloropropene	3.3	0.015	Not Detected	Not Detected
Toluene	3.3	0.012	280	1.0
trans-1,3-Dichloropropene	3.3	0.015	Not Detected	Not Detected
1,1,2-Trichloroethane	3.3	0.018	Not Detected	Not Detected
Tetrachloroethene	310	2.1	36000 E	240 E
Ethylene Dibromide	3.3	0.025	Not Detected	Not Detected
Chlorobenzene	3.3	0.015	Not Detected	Not Detected
Ethyl Benzene	3.3	0.014	Not Detected	Not Detected
m,p-Xylene	3.3	0.014	8.6	0.036
o-Xylene	3.3	0.014	3.5	0.015
Styrene	3.3	0.014	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	3.3	0.022	Not Detected	Not Detected
1,3,5-Trimethylbenzene	3.3	0.016	Not Detected	Not Detected
1,2,4-Trimethylbenzene	3.3	0.016	Not Detected	Not Detected
1,3-Dichlorobenzene	3.3	0.019	Not Detected	Not Detected
1,4-Dichlorobenzene	3.3	0.019	Not Detected	Not Detected
Chlorotoluene	3.3	0.017	Not Detected	Not Detected
1,2-Dichlorobenzene	3.3	0.019	Not Detected	Not Detected
1,2,4-Trichlorobenzene	3.3	0.024	Not Detected	Not Detected
Hexachlorobutadiene	3.3	0.034	Not Detected	Not Detected

E = Exceeds instrument calibration range, but within linear range.

Container Type: 6 Liter SUMMA Canister

Comments: The second file name and dilution factor are for Tetrachloroethene only.

Surrogates	% Recovery	Method Limits
Octafluorotoluene	100 / 108	70-130
Toluene-d8	102 / 104	70-130
4-Bromofluorobenzene	93 / 86	70-130

AIR TOXICS LTD.

SAMPLE NAME: P-4D
ID#: 9308055-04A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	5081706	**Date of Collection:**	8/5/93
Dil. Factor:	14	**Date of Analysis:**	8/17/93

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	7.0	0.034	Not Detected	Not Detected
Freon 114	7.0	0.048	Not Detected	Not Detected
Chloromethane	7.0	0.014	Not Detected	Not Detected
Vinyl Chloride	7.0	0.017	Not Detected	Not Detected
Bromomethane	7.0	0.027	Not Detected	Not Detected
Chloroethane	7.0	0.018	Not Detected	Not Detected
Freon 11	7.0	0.038	Not Detected	Not Detected
1,1-Dichloroethene	7.0	0.027	4900 E	19 E
Freon 113	7.0	0.052	12	0.090
Methylene Chloride	7.0	0.024	Not Detected	Not Detected
1,1-Dichloroethane	7.0	0.028	28	0.11
cis-1,2-Dichloroethene	7.0	0.027	420	1.6
Chloroform	7.0	0.033	Not Detected	Not Detected
1,1,1-Trichloroethane	7.0	0.037	36	0.19
Carbon Tetrachloride	7.0	0.037	Not Detected	Not Detected
Benzene	7.0	0.022	44	0.14
1,2-Dichloroethane	7.0	0.028	Not Detected	Not Detected
Trichloroethene	7.0	0.037	11000 E	58 E
1,2-Dichloropropane	7.0	0.032	9.2	0.042
cis-1,3-Dichloropropene	7.0	0.031	Not Detected	Not Detected
Toluene	7.0	0.026	1300	4.8
trans-1,3-Dichloropropene	7.0	0.031	Not Detected	Not Detected
1,1,2-Trichloroethane	7.0	0.037	Not Detected	Not Detected
Tetrachloroethene	7.0	0.046	57000 E	380 E
Ethylene Dibromide	7.0	0.053	Not Detected	Not Detected
Chlorobenzene	7.0	0.031	Not Detected	Not Detected
Ethyl Benzene	7.0	0.030	Not Detected	Not Detected
m,p-Xylene	7.0	0.030	Not Detected	Not Detected
o-Xylene	7.0	0.030	Not Detected	Not Detected
Styrene	7.0	0.029	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	7.0	0.047	Not Detected	Not Detected
1,3,5-Trimethylbenzene	7.0	0.034	Not Detected	Not Detected
1,2,4-Trimethylbenzene	7.0	0.034	Not Detected	Not Detected
1,3-Dichlorobenzene	7.0	0.041	Not Detected	Not Detected
1,4-Dichlorobenzene	7.0	0.041	Not Detected	Not Detected
Chlorotoluene	7.0	0.035	Not Detected	Not Detected
1,2-Dichlorobenzene	7.0	0.041	Not Detected	Not Detected
1,2,4-Trichlorobenzene	7.0	0.051	Not Detected	Not Detected
Hexachlorobutadiene	7.0	0.073	Not Detected	Not Detected

E = Exceeds instrument calibration range, but within linear range.

Container Type: 6 Liter SUMMA Canister

Surrogates	% Recovery	Method Limits
Octafluorotoluene	100	70-130
Toluene-d8	103	70-130
4-Bromofluorobenzene	91	70-130

AIR TOXICS LTD.

SAMPLE NAME: CH-10
ID#: 9308055-05A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	**5081408**	**Date of Collection:**	**8/5/93**
Dil. Factor:	**1.6**	**Date of Analysis:**	**8/14/93**

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	0.80	0.004	Not Detected	Not Detected
Freon 114	0.80	0.005	Not Detected	Not Detected
Chloromethane	0.80	0.002	Not Detected	Not Detected
Vinyl Chloride	0.80	0.002	Not Detected	Not Detected
Bromomethane	0.80	0.003	Not Detected	Not Detected
Chloroethane	0.80	0.002	Not Detected	Not Detected
Freon 11	0.80	0.004	Not Detected	Not Detected
1,1-Dichloroethene	0.80	0.003	Not Detected	Not Detected
Freon 113	0.80	0.006	Not Detected	Not Detected
Methylene Chloride	0.80	0.003	Not Detected	Not Detected
1,1-Dichloroethane	0.80	0.003	Not Detected	Not Detected
cis-1,2-Dichloroethene	0.80	0.003	Not Detected	Not Detected
Chloroform	0.80	0.004	Not Detected	Not Detected
1,1,1-Trichloroethane	0.80	0.004	Not Detected	Not Detected
Carbon Tetrachloride	0.80	0.004	Not Detected	Not Detected
Benzene	0.80	0.002	Not Detected	Not Detected
1,2-Dichloroethane	0.80	0.003	Not Detected	Not Detected
Trichloroethene	0.80	0.004	Not Detected	Not Detected
1,2-Dichloropropane	0.80	0.004	Not Detected	Not Detected
cis-1,3-Dichloropropene	0.80	0.004	Not Detected	Not Detected
Toluene	0.80	0.003	Not Detected	Not Detected
trans-1,3-Dichloropropene	0.80	0.004	Not Detected	Not Detected
1,1,2-Trichloroethane	0.80	0.004	Not Detected	Not Detected
Tetrachloroethene	0.80	0.005	Not Detected	Not Detected
Ethylene Dibromide	0.80	0.006	Not Detected	Not Detected
Chlorobenzene	0.80	0.004	Not Detected	Not Detected
Ethyl Benzene	0.80	0.003	Not Detected	Not Detected
m,p-Xylene	0.80	0.003	Not Detected	Not Detected
o-Xylene	0.80	0.003	Not Detected	Not Detected
Styrene	0.80	0.003	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	0.80	0.005	Not Detected	Not Detected
1,3,5-Trimethylbenzene	0.80	0.004	Not Detected	Not Detected
1,2,4-Trimethylbenzene	0.80	0.004	Not Detected	Not Detected
1,3-Dichlorobenzene	0.80	0.005	Not Detected	Not Detected
1,4-Dichlorobenzene	0.80	0.005	Not Detected	Not Detected
Chlorotoluene	0.80	0.004	Not Detected	Not Detected
1,2-Dichlorobenzene	0.80	0.005	Not Detected	Not Detected
1,2,4-Trichlorobenzene	0.80	0.006	Not Detected	Not Detected
Hexachlorobutadiene	0.80	0.008	Not Detected	Not Detected

Container Type: 6 Liter SUMMA Canister

Surrogates	% Recovery	Method Limits
Octafluorotoluene	103	70-130
Toluene-d8	103	70-130
4-Bromofluorobenzene	88	70-130

AIR TOXICS LTD.

SAMPLE NAME: Method Spike
ID#: 9308055-06A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	5081702		**Date of Collection: NA**
Dil. Factor:	1.0		**Date of Analysis: 8/17/93**

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	% Recovery
Freon 12	0.50	0.002	96
Freon 114	0.50	0.003	96
Chloromethane	0.50	0.001	96
Vinyl Chloride	0.50	0.001	97
Bromomethane	0.50	0.002	99
Chloroethane	0.50	0.001	92
Freon 11	0.50	0.003	94
1,1-Dichloroethene	0.50	0.002	99
Freon 113	0.50	0.004	98
Methylene Chloride	0.50	0.002	92
1,1-Dichloroethane	0.50	0.002	96
cis-1,2-Dichloroethene	0.50	0.002	92
Chloroform	0.50	0.002	97
1,1,1-Trichloroethane	0.50	0.003	99
Carbon Tetrachloride	0.50	0.003	92
Benzene	0.50	0.002	98
1,2-Dichloroethane	0.50	0.002	94
Trichloroethene	0.50	0.003	101
1,2-Dichloropropane	0.50	0.002	96
cis-1,3-Dichloropropene	0.50	0.002	86
Toluene	0.50	0.002	103
trans-1,3-Dichloropropene	0.50	0.002	78
1,1,2-Trichloroethane	0.50	0.003	91
Tetrachloroethene	0.50	0.003	99
Ethylene Dibromide	0.50	0.004	84
Chlorobenzene	0.50	0.002	86
Ethyl Benzene	0.50	0.002	94
m,p-Xylene	0.50	0.002	92
o-Xylene	0.50	0.002	90
Styrene	0.50	0.002	78
1,1,2,2-Tetrachloroethane	0.50	0.003	84
1,3,5-Trimethylbenzene	0.50	0.002	83
1,2,4-Trimethylbenzene	0.50	0.002	78
1,3-Dichlorobenzene	0.50	0.003	54 Q
1,4-Dichlorobenzene	0.50	0.003	60 Q
Chlorotoluene	0.50	0.003	Not Spiked
1,2-Dichlorobenzene	0.50	0.003	62 Q
1,2,4-Trichlorobenzene	0.50	0.004	47 Q
Hexachlorobutadiene	0.50	0.005	87

Q = Exceeds Quality Control limits of 70% to 130%.

Container Type: NA

Surrogates	% Recovery	Method Limits
Octafluorotoluene	98	70-130
Toluene-d8	102	70-130
4-Bromofluorobenzene	98	70-130

AIR TOXICS LTD.

SAMPLE NAME: Lab Blank
ID#: 9308055-07A
EPA METHOD TO-14 GC/MS Full Scan

File Name:	**5081403**	**Date of Collection:**	**NA**
Dil. Factor:	**1.0**	**Date of Analysis:**	**8/14/93**

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	0.50	0.002	Not Detected	Not Detected
Freon 114	0.50	0.003	Not Detected	Not Detected
Chloromethane	0.50	0.001	Not Detected	Not Detected
Vinyl Chloride	0.50	0.001	Not Detected	Not Detected
Bromomethane	0.50	0.002	Not Detected	Not Detected
Chloroethane	0.50	0.001	Not Detected	Not Detected
Freon 11	0.50	0.003	Not Detected	Not Detected
1,1-Dichloroethene	0.50	0.002	Not Detected	Not Detected
Freon 113	0.50	0.004	Not Detected	Not Detected
Methylene Chloride	0.50	0.002	Not Detected	Not Detected
1,1-Dichloroethane	0.50	0.002	Not Detected	Not Detected
cis-1,2-Dichloroethene	0.50	0.002	Not Detected	Not Detected
Chloroform	0.50	0.002	Not Detected	Not Detected
1,1,1-Trichloroethane	0.50	0.003	Not Detected	Not Detected
Carbon Tetrachloride	0.50	0.003	Not Detected	Not Detected
Benzene	0.50	0.002	Not Detected	Not Detected
1,2-Dichloroethane	0.50	0.002	Not Detected	Not Detected
Trichloroethene	0.50	0.003	Not Detected	Not Detected
1,2-Dichloropropane	0.50	0.002	Not Detected	Not Detected
cis-1,3-Dichloropropene	0.50	0.002	Not Detected	Not Detected
Toluene	0.50	0.002	Not Detected	Not Detected
trans-1,3-Dichloropropene	0.50	0.002	Not Detected	Not Detected
1,1,2-Trichloroethane	0.50	0.003	Not Detected	Not Detected
Tetrachloroethene	0.50	0.003	Not Detected	Not Detected
Ethylene Dibromide	0.50	0.004	Not Detected	Not Detected
Chlorobenzene	0.50	0.002	Not Detected	Not Detected
Ethyl Benzene	0.50	0.002	Not Detected	Not Detected
m,p-Xylene	0.50	0.002	Not Detected	Not Detected
o-Xylene	0.50	0.002	Not Detected	Not Detected
Styrene	0.50	0.002	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	0.50	0.003	Not Detected	Not Detected
1,3,5-Trimethylbenzene	0.50	0.002	Not Detected	Not Detected
1,2,4-Trimethylbenzene	0.50	0.002	Not Detected	Not Detected
1,3-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
1,4-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
Chlorotoluene	0.50	0.003	Not Detected	Not Detected
1,2-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
1,2,4-Trichlorobenzene	0.50	0.004	Not Detected	Not Detected
Hexachlorobutadiene	0.50	0.005	Not Detected	Not Detected

Container Type: NA

Surrogates	% Recovery	Method Limits
Octafluorotoluene	104	70-130
Toluene-d8	100	70-130
4-Bromofluorobenzene	87	70-130

AIR TOXICS LTD.

SAMPLE NAME: Lab Blank
ID#: 9308055-07B
EPA METHOD TO-14 GC/MS Full Scan

File Name:	5081604		**Date of Collection:** NA
Dil. Factor:	1.0		**Data of Analysis:** 8/16/93

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	0.50	0.002	Not Detected	Not Detected
Freon 114	0.50	0.003	Not Detected	Not Detected
Chloromethane	0.50	0.001	Not Detected	Not Detected
Vinyl Chloride	0.50	0.001	Not Detected	Not Detected
Bromomethane	0.50	0.002	Not Detected	Not Detected
Chloroethane	0.50	0.001	Not Detected	Not Detected
Freon 11	0.50	0.003	Not Detected	Not Detected
1,1-Dichloroethene	0.50	0.002	Not Detected	Not Detected
Freon 113	0.50	0.004	Not Detected	Not Detected
Methylene Chloride	0.50	0.002	Not Detected	Not Detected
1,1-Dichloroethane	0.50	0.002	Not Detected	Not Detected
cis-1,2-Dichloroethene	0.50	0.002	Not Detected	Not Detected
Chloroform	0.50	0.002	Not Detected	Not Detected
1,1,1-Trichloroethane	0.50	0.003	Not Detected	Not Detected
Carbon Tetrachloride	0.50	0.003	Not Detected	Not Detected
Benzene	0.50	0.002	Not Detected	Not Detected
1,2-Dichloroethane	0.50	0.002	Not Detected	Not Detected
Trichloroethene	0.50	0.003	Not Detected	Not Detected
1,2-Dichloropropane	0.50	0.002	Not Detected	Not Detected
cis-1,3-Dichloropropene	0.50	0.002	Not Detected	Not Detected
Toluene	0.50	0.002	Not Detected	Not Detected
trans-1,3-Dichloropropene	0.50	0.002	Not Detected	Not Detected
1,1,2-Trichloroethane	0.50	0.003	Not Detected	Not Detected
Tetrachloroethene	0.50	0.003	Not Detected	Not Detected
Ethylene Dibromide	0.50	0.004	Not Detected	Not Detected
Chlorobenzene	0.50	0.002	Not Detected	Not Detected
Ethyl Benzene	0.50	0.002	Not Detected	Not Detected
m,p-Xylene	0.50	0.002	Not Detected	Not Detected
o-Xylene	0.50	0.002	Not Detected	Not Detected
Styrene	0.50	0.002	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	0.50	0.003	Not Detected	Not Detected
1,3,5-Trimethylbenzene	0.50	0.002	Not Detected	Not Detected
1,2,4-Trimethylbenzene	0.50	0.002	Not Detected	Not Detected
1,3-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
1,4-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
Chlorotoluene	0.50	0.003	Not Detected	Not Detected
1,2-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
1,2,4-Trichlorobenzene	0.50	0.004	Not Detected	Not Detected
Hexachlorobutadiene	0.50	0.005	Not Detected	Not Detected

Container Type: NA

Surrogates	% Recovery	Method Limits
Octafluorotoluene	**104**	**70-130**
Toluene-d8	**104**	**70-130**
4-Bromofluorobenzene	**89**	**70-130**

AIR TOXICS LTD.

SAMPLE NAME: Lab Blank
ID#: 9308055-07C
EPA METHOD TO-14 GC/MS Full Scan

File Name: 5081703 **Date of Collection: NA**
Dil. Factor: 1.0 **Date of Analysis: 8/17/93**

Compound	Det. Limit (ppbv)	Det. Limit (uG/L)	Amount (ppbv)	Amount (uG/L)
Freon 12	0.50	0.002	Not Detected	Not Detected
Freon 114	0.50	0.003	Not Detected	Not Detected
Chloromethane	0.50	0.001	Not Detected	Not Detected
Vinyl Chloride	0.50	0.001	Not Detected	Not Detected
Bromomethane	0.50	0.002	Not Detected	Not Detected
Chloroethane	0.50	0.001	Not Detected	Not Detected
Freon 11	0.50	0.003	Not Detected	Not Detected
1,1-Dichloroethene	0.50	0.002	Not Detected	Not Detected
Freon 113	0.50	0.004	Not Detected	Not Detected
Methylene Chloride	0.50	0.002	Not Detected	Not Detected
1,1-Dichloroethane	0.50	0.002	Not Detected	Not Detected
cis-1,2-Dichloroethene	0.50	0.002	Not Detected	Not Detected
Chloroform	0.50	0.002	Not Detected	Not Detected
1,1,1-Trichloroethane	0.50	0.003	Not Detected	Not Detected
Carbon Tetrachloride	0.50	0.003	Not Detected	Not Detected
Benzene	0.50	0.002	Not Detected	Not Detected
1,2-Dichloroethane	0.50	0.002	Not Detected	Not Detected
Trichloroethene	0.50	0.003	Not Detected	Not Detected
1,2-Dichloropropane	0.50	0.002	Not Detected	Not Detected
cis-1,3-Dichloropropene	0.50	0.002	Not Detected	Not Detected
Toluene	0.50	0.002	Not Detected	Not Detected
trans-1,3-Dichloropropene	0.50	0.002	Not Detected	Not Detected
1,1,2-Trichloroethane	0.50	0.003	Not Detected	Not Detected
Tetrachloroethene	0.50	0.003	Not Detected	Not Detected
Ethylene Dibromide	0.50	0.004	Not Detected	Not Detected
Chlorobenzene	0.50	0.002	Not Detected	Not Detected
Ethyl Benzene	0.50	0.002	Not Detected	Not Detected
m,p-Xylene	0.50	0.002	Not Detected	Not Detected
o-Xylene	0.50	0.002	Not Detected	Not Detected
Styrene	0.50	0.002	Not Detected	Not Detected
1,1,2,2-Tetrachloroethane	0.50	0.003	Not Detected	Not Detected
1,3,5-Trimethylbenzene	0.50	0.002	Not Detected	Not Detected
1,2,4-Trimethylbenzene	0.50	0.002	Not Detected	Not Detected
1,3-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
1,4-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
Chlorotoluene	0.50	0.003	Not Detected	Not Detected
1,2-Dichlorobenzene	0.50	0.003	Not Detected	Not Detected
1,2,4-Trichlorobenzene	0.50	0.004	Not Detected	Not Detected
Hexachlorobutadiene	0.50	0.005	Not Detected	Not Detected

Container Type:

Surrogates	% Recovery	Method Limits
Octafluorotoluene	**103**	**70-130**
Toluene-d8	**103**	**70-130**
4-Bromofluorobenzene	**87**	**70-130**

AIR TOXICS LTD.
AN ENVIRONMENTAL ANALYTICAL LABORATORY

180 BLUE RAVINE ROAD, SUITE B
FOLSOM, CA 95630
(916) 985-1000 • FAX (916) 985-1020

CHAIN OF CUSTODY RECORD

Page 1 of ___

PROJECT # SAC28722.55.10 PO # _____ COLLECTED BY (Signature) Kevin A. Roberts

REMARKS CH2M HILL DAVIS SITE

*NO DILUTION — REPORT RESULTS IN µg/L & PPBV

	FIELD SAMPLE I.D.#	SAMPLING MEDIA (Tenax, canister etc.)	DATE/TIME	ANALYSIS	VAC./PRESSURE	LAB I.D. #
01A	P-3D	#11309	08/05/93 1220	EPA TO-14*	13.5" Hg	
02A	P-1D	# 10786	08/05/93 1155	" *	9.5" Hg	
03A	P-33D	# 10981	08/05/93 1220	" *	13.5" Hg	

RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME	RELINQUISHED BY: DATE/TIME	RECEIVED BY: DATE/TIME
Joan Brooks 8/6/93	L. Robinson ATL 8/9/11 1100 AM		

LAB USE ONLY

SHIPPER NAME	AIR BILL #	OPENED BY: DATE/TIME	TEMP(°C)	CONDITION

REMARKS _____

CH2M HILL
QUALITY ANALYTICAL LABORATORIES

CHAIN OF CUSTODY RECORD AND AGREEMENT TO PERFORM SERVICES

CH2M HILL Project #: SAC28722.55.10
Purchase Order #:
Project Name: Davis
Company Name/CH2M HILL Office: CH2M Hill /RDD
Project Manager & Phone #: Mr. [X] Ms. [ ] Dr. [ ] Gerald Vogt
Report Copy to: Loren, Krook
Requested Completion Date: [illegible]
Sampling Requirements: SDWA [ ] NPDES [ ] RCRA [ ] OTHER ____
Sample Disposal: Dispose [ ] Return [ ]

LAB TEST CODES

ANALYSES REQUESTED: EPA TO-14*

SHADED AREA – FOR LAB USE ONLY: Lab 1 # | Lab 2 # | Quote # | Kit Request # | Project # | No. of Samples | Page | of | COC Rev | Login | LIMS Ver | Ack Gen

	Sampling Date	Sampling Time	Type COMP	Type GRAB	Matrix WATER	Matrix SOIL	CLIENT SAMPLE ID (9 CHARACTERS)	# OF CONTAINERS	EPA TO-14*	REMARKS	LAB 1 ID	LAB 2 ID
HA	08/05/93	1230		X			P-4D	1	X CAN# 13858	*No DILUTION		10.5
SA	08/05/93	1500		X			CH-10	1	X CAN# 13846.			5.0
							12955	1	CAN WAS NOT USED			
							11887	1	CAN WAS NOT USED			

Sampled By & Title (Please sign and print name): Loren Krook LOREN KROOK	Date/Time: 8/5/93 1500	Relinquished By (Please sign and print name): Loren Krook	Date/Time: 8/6/93 1600
Received By (Please sign and print name): L. Robinson ATL	Date/Time: 8/9/93 1100	Relinquished By (Please sign and print name):	Date/Time:
Received By (Please sign and print name):	Date/Time:	Relinquished By (Please sign and print name):	Date/Time:
Received By (Please sign and print name):	Date/Time:	Shipped Via: UPS BUS Fed-Ex Hand Other	Shipping #:
Work Authorized By (Please sign and print name):	Remarks: *REPORT RESULTS IN µg/L & PPbV		

HAZWRAP/NESSA: Y N
QC Level: 1 2 3 Other: ____
COC Rec | ICE
Ana Req | TEMP
Cust Seal | Ph

Instructions [illegible] Agreement Provisions on Reverse Side

DISTRIBUTION: ORIGINAL - LAB, Yellow [illegible], Pink - Client

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Sara Monteith/CH2M HILL, Redding
Fritz Carlson/CH2M HILL, Redding
Loren Krook/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Air Permeability Testing
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.18

Purpose

This technical memorandum provides a summary of the installation of soil vapor monitoring wells (SVMWs), testing equipment and procedures, test results, and interpretation at the Davis Site. The purpose of the air permeability testing program was to quantify the properties of the vadose zone that control the movement of air. The testing program described herein was conducted as part of an investigation of vadose zone and saturated zone contamination at the Davis Site. Volatile organic compounds (VOCs) have been detected in gas samples taken from the vadose zone. Such chemicals could be a long-term source of contamination for the groundwater in the underlying saturated zone. VOCs may be readily extracted from the vadose zone using soil vapor extraction (SVE) methods. This testing program was performed to provide preliminary information that could be used to design the SVE system at the Davis Site.

Introduction

Terminology

In this discussion, the term "permeability" refers to the intrinsic permeability of the porous medium. The term "air conductivity" refers to the ability of the medium to conduct air and is analogous with the term "hydraulic conductivity" that is used to measure the ability of the porous medium to conduct water. The intrinsic permeability is independent of the moisture content of the porous medium and is independent of the fluid moving through the porous medium. It is well established that the hydraulic conductivity of a porous medium is a function of moisture content. The wetter the pores get, the higher the hydraulic conductivity. The maximum hydraulic

conductivity is when all the pores are full of water; this is the saturated hydraulic conductivity that is typically measured in aquifer tests. In a similar way, the conductivity to air moving in the vadose zone is sensitive to the moisture content in the vadose zone. As the pores become wetter, the conductivity to air will decrease. Conversely, as the pores become drier, the permeability to air will increase.

The "air transmissivity" is equal to the air conductivity times the thickness of the permeable zone.

In this discussion the term "aerifer" is used to describe a geologic unit through which air can flow to an extraction well. This term is analogous with the term "aquifer" as used in the saturated zone. Similarly, the term "aeritard" is used to describe a geologic unit that retards the flow of air. Aeritard is analogous with the term aquitard used in the saturated flow of groundwater.

Description of Field Activities

The air permeability testing was conducted from January 6 through January 14, 1993. This was a period of heavy rainfall at the site. Rainfall amount and test dates are shown in Table B-1.

Table B-1
Rainfall at Davis, California
January 6 through January 14, 1993

Date	Rainfall (in.)	Air Permeability Test
January 6	0.24	CH-1
January 7	2.19	CH-4
January 8	0.30	None
January 9	0.04	None
January 10	0.04	None
January 11	0	None
January 12	0	None
January 13	2.97	CH-5
January 14	0.68	None

The configuration for evaluating air permeability at the Davis Site consists of the following:

- Five SVMWs, CH-1 through CH-5

- Four "shallow" piezometers, P-1S, and P-3S through P-5S (adjacent to CH-1, and CH-3 through CH-5, respectively)
- One intermediate-depth piezometer, P-2M (adjacent to CH-2)
- Four "deep" piezometers, P-1D, and P-3D through P-5D (adjacent to CH-1, and CH-3 through CH-5, respectively

Well locations were selected using results of the shallow soil gas sampling described in Appendix A, Soil Gas Investigation (locations of soil gas sampling given in Figure A-1). The wells were placed in boreholes advanced with an 8-inch hollow-stem auger by Westex Drilling of West Sacramento. The piezometers were placed in an adjacent 8-inch borehole. Standard Penetration Tests were performed at approximate 5-foot intervals, and soil samples were logged in general accordance with the Unified Soil Classification System (ASTM D 2488). Locations and elevations of the wells and piezometers were surveyed by CH2M HILL using nearby existing wells as a reference. Boring logs and well construction diagrams are included in Appendixes Q and S, Lithologic and Geophysical Logs, and Well Construction Data, respectively.

The SVMWs consist of 2-inch-diameter Schedule 40 PVC with a screened interval of 10 feet; except CH-2, with a screened interval of 2 feet. The piezometers are constructed of 1-inch-diameter Schedule 40 PVC, with a screened interval of 2 feet for shallow piezometers, 5 feet for the intermediate-depth piezometer, and 10 feet for deep piezometers. A summary of well and piezometer details is provided in Table B-2. Soil vapor monitoring well and piezometer locations are shown in Figure B-4 (page B-13).

Groundwater levels were measured prior to and following air permeability testing. The screened interval, of the deep piezometers were submerged, and therefore unavailable for monitoring during testing. A summary of groundwater measurements is provided in Table B-3 (wells not listed are screened above the groundwater table.).

Subsurface Conditions

In general the subsurface conditions at the Davis Site consist of clay with moderately continuous lenses of sand and silty sand, and less common lenses of gravel. The soil profile has been divided roughly into five zones, "A" through "E". The upper zone, designated the A zone, extends from the ground surface to 65 feet below ground surface (bgs), and contains one or two layers with increased permeability (aerifers). The first is located between 13 and 18 feet bgs, and the second is between 25 and 35 feet bgs. The B zone is located between 65 and 95 feet; the C zone between 95 and 145 feet bgs; the D zone between 145 and 195 feet bgs; and the E zones between 195 and 245 feet bgs. These zones are quite variable in thickness and are somewhat discontinuous laterally. The SVMWs and their associated piezometers are screened within the A aerifer and the B aquifer.

Table B-2 Summary of Well and Piezometer Details					
Well/ Piezometer No.	Description	Elevation (feet msl)	Screened Interval (feet bgs)	Gravel Pack Interval (feet bgs)	Description of Soil Adjacent to the Screened Interval
CH-1	2-inch well	26.4	25 to 35	21 to 37	Sandy Silt/Silty Sand
P-1S	1-inch piezometer	26.4	14 to 16	13.5 to 17	Clay w/trace Sand
P-1D	1-inch piezometer	26.4	48 to 58	43 to 60	Clay w/Sand
CH-2	2-inch well	25.9	14 to 16	13.5 to 17	Silty Sand/Sandy Silt
P-2M	1-inch piezometer	25.9	30 to 35	28 to 36	Sand and Gravel w/Silt
CH-3	2-inch well	25.6	22 to 32	20 to 33	Sand w/Gravel and Silt
P-3S	1-inch piezometer	25.6	15 to 17	14.5 to 18	Sand and Silt
P-3D	1-inch piezometer	25.6	48 to 58	46 to 60	Clay
CH-4	2-inch well	25.3	27 to 37	26 to 40	Sand w/Clay and Silt
P-4S	1-inch piezometer	25.3	17 to 19	15 to 20	Clay
P-4D	1-inch piezometer	25.3	45 to 55	41 to 56	Clay
CH-5	2-inch well	28.2	28 to 38	26 to 39	Clayey Sand/Clayey Gravel
P-5S	1-inch piezometer	28.2	18 to 20	17 to 22	Sandy Clay
P-5D	1-inch piezometer	28.2	45 to 55	43 to 55.3	Clay

Table B-3 Summary of Groundwater Measurements				
Well/Piezometer No.	Depth to Groundwater (feet bgs)		Elevation of Groundwater (feet msl)	
	12/14/92	1/14/92	12/14/92	1/14/93
P-1D	39.85	36.17	-13.5	-9.8
P-3D	38.76	35.32	-13.2	-9.7
CH-4	36.47	35.11	-11.2	-9.8
P-4D	38.63	35.32	-13.3	-10.0
P-5D	40.70	38.42	-12.5	-10.2

Test Equipment and Procedure

In general,the air permeability tests were performed by removing air at a constant rate from a selected SVMW, termed an "extraction well," while monitoring transient

subsurface pressures at selected SVMWs and piezometers. Effluent vapors were treated using carbon filtration prior to discharge to the atmosphere.

Test Equipment

The test equipment used during air permeability testing consisted of a vacuum source at the extraction well and pressure monitoring instruments at SVMWs and piezometers. Additional test equipment included an air flow rate measuring device and emissions treatment. A listing of the specific equipment used is given below:

- Vacuum source was a Roots/Dresser Universal RAI Rotary Lobe Blower powered by a 10-kilowatt generator (single-phase, 240 volts, 30 amps).

- Flow rate was measured with a Delta Tube^{R} averaging pitot tube system with direct reading of actual cubic feet per minute (acfm) air flow using a Mid-West Instrument Model 130 differential pressure gage (30 to 130 acfm range).

- Drawdown at the extraction well was measured with a mercury manometer with a 12-inch range of mercury.

- Drawdown at the SVMWs and piezometers selected for observation was measured using various combinations of U-tube manometers (24-inch water range), incline manometers (3-inch water range), and Magnehelic gages (2-inch, 20-inch, and 80-inch water ranges). Connections to the SVMWs and piezometers were fabricated in the field as required.

- Ambient pressure was monitored with a Hermit Model C data logger with a PXD-360 barometric pressure transducer (8 to 16 pounds per square inch actual (psia) range).

- Emissions were treated with a granulated activated carbon filter at the discharge of the blower.

- System "plumbing" consisted of air stream dilution valves (integral to the blower unit), 2-inch-diameter rigid wall pump suction hoses with quick-connect camlock connectors, and a ball valve at the extraction well to isolate the blower system from the wellhead.

- Connections of the blower to the extraction well were made with the camlock hoses described above.

Procedure

The air permeability testing procedure used at the Davis Site is given below. Modification to this procedure may be required for differing site conditions.

1. Seal each SVMW and piezometer and connect the selected pressure measuring device. Check for leaks. Zero the pressure measuring device, record reading, and note time and location. Monitor pressures for a time sufficient to establish background conditions. Record ambient atmospheric pressure each time the wellhead pressures are recorded.

2. Connect the blower to the extraction well and begin preliminary tests to measure extraction and monitoring well responses to varying applied vacuums ("step test").

   Apply maximum vacuum at the extraction well and record the corresponding flow rate. At approximate 2-minute intervals, reduce the applied pressure until approximately 75, 50 and 25 percent of the original pressure is produced. Note the flow rate and corresponding pressure each time. Reverse test and step pressure back up. Repeat this cycle until consistent results have been achieved.

3. Allow subsurface pressures at the observation wells to return to background levels. If necessary, relocate manometers and gages to optimize instrument scales to the expected range of pressure decrease during longer-term air extraction.

4. Based on the results of the step test, determine the optimum extraction flow rate and pressure. Factors influencing this selection will include extraction well screen saturation due to water table upwelling, pressure and flow rate measuring instrument scales, emissions treatment unit capacity, and blower limitations. Generally, select the highest practical vacuum that will result in a stable, measurable flow rate. Allow for adjustment of flow and pressure during the test. Measurements may drift from initial values. Avoid beginning the test with adjusting valves in full-open of full-closed positions.

5. Begin the pressure drawdown test (air permeability test).

   Extract air at a constant rate and measure pressure decreases at the extraction and observation wells as functions of time. Take readings at minimum 10-minute intervals for the first log cycle (100 minutes), and at minimum 30-minute intervals for the duration of the test. Plot time versus pressure decrease data for each well using a logarithmic scale for time.

6. Continue the test for at least 4 hours or until observation well pressures stabilize.

7. At the conclusion of the test, close valve between the extraction well and the vacuum, but maintain a sealed system. Monitor the "recovery"

of the extraction well and observation well until the residual vacuum is less than 10 percent of the maximum applied vacuum.

A step test was performed at Wells CH-1, CH-4, and CH-5. The range of flow for the step tests varied from 10 to 100 percent of the full vacuum of the blower. Results are shown on plots in Attachment B-1 at the back of this appendix.

Following air permeability testing at each extraction well, recovery was monitored for 1 to 2 hours. Plots of well recovery are attached at the back of this appendix. (Recovery at CH-5 was complete within 10 minutes. Therefore, no plot of recovery at CH-5 is provided.)

Test Results

The data from the tests are presented in Figures B-1 through B-3 and in Tables B-4 through B-6. Several key findings can be observed by examination of the test results:

- Drawdown was observed in monitoring points located several hundred feet from the pumping wells.
- At the same radial distance from the pumping well, there was less drawdown observed in the unpumped zone compared to the pumped zone.
- The apparent extent of influence of pumping was larger in the CH-5 tests than in the others, possibly due to the sealing effect of infiltrating rainfall.

Table B-4
Summary of Air Permeability Test at Extraction Well CH-1

Date: 1/6/93
Duration: ≈500 minutes (08:45 to 16:12)
Flow: 110 acfm
Drawdown (at extraction well): 21.8 inches H_2O

Monitoring Well No.	Distance from CH-1 to Monitoring Well (feet)	Drawdown Measured After 500 Minutes (inches H_2O)
P-1S	4.0	3.9
CH-2	60.1	1.42
P-2M	60.5	1.63
CH-3	103.4	0.85
P-3S	104.5	1.05
CH-4	179.8	0.18
CH-5	234.0	0.10

Note: Drawdown is used here as a measure of the difference between atmospheric conditions and the vacuum measured in the aerifer.

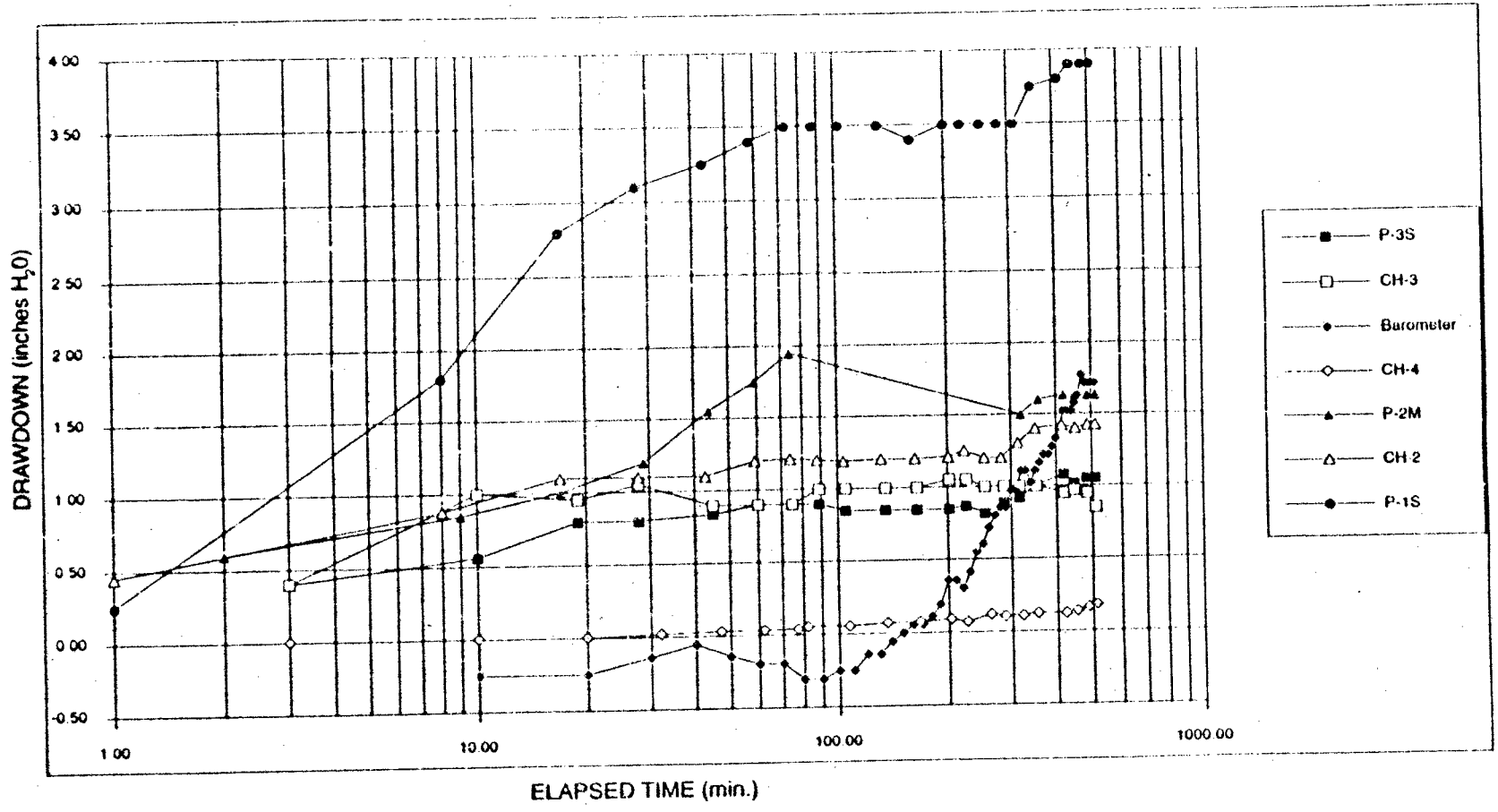


FIGURE B-1
AIR PERMEABILITY TEST AT CH-1
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

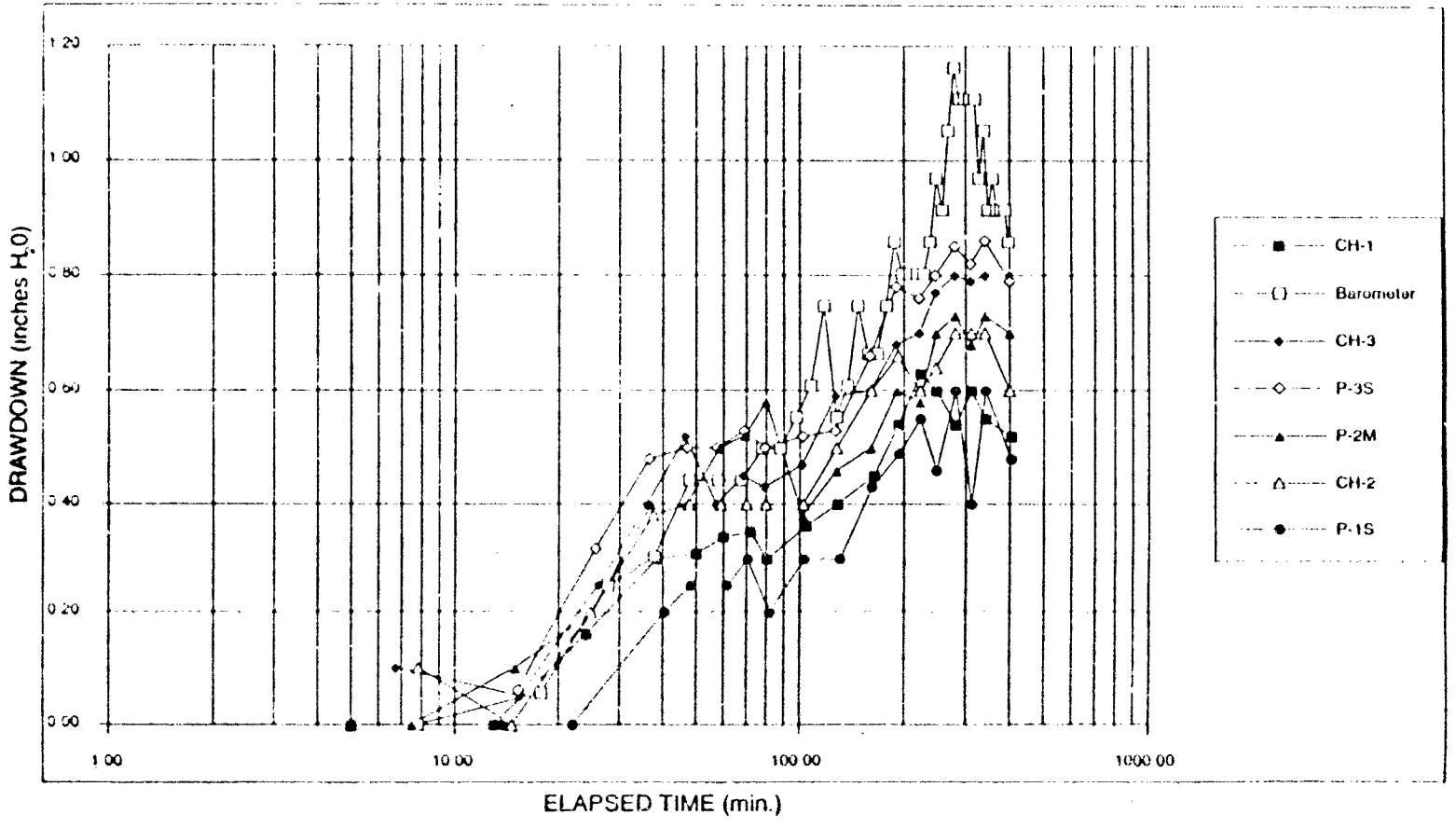


FIGURE B-2
AIR PERMEABILITY TEST AT CH-4
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE

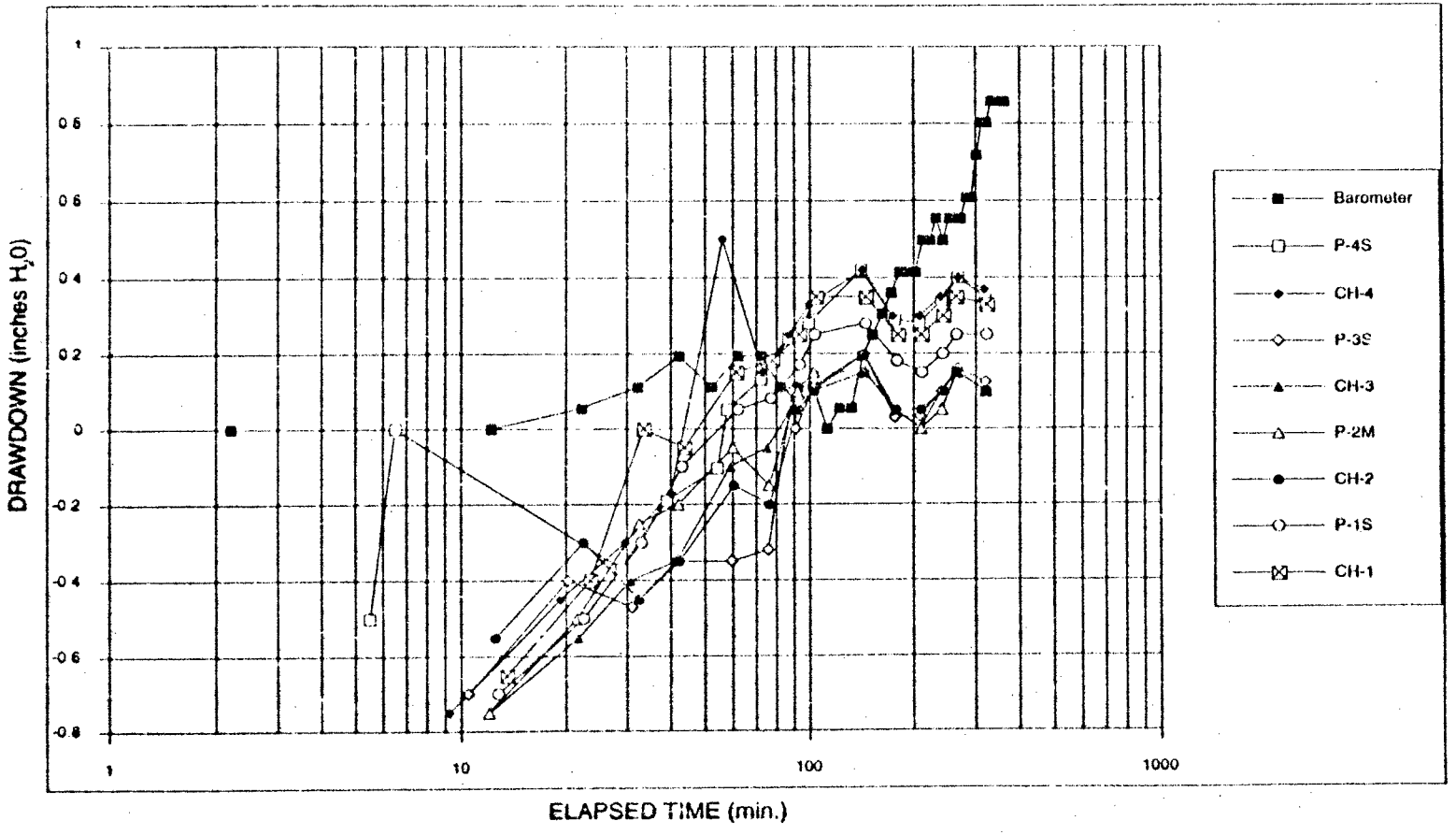


FIGURE B-3
AIR PERMEABILITY TEST AT CH-5
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_245

Table B-5
Summary of Air Permeability Test at Extraction Well CH-4

Date: 1/7/93
Duration: ≈400 minutes (10:45 to 16:50)
Flow: 70 acfm
Drawdown (at extraction well): 84.3 inches H_2O after 50 minutes, decreased to 54.0 inches H_2O after 400 minutes.

Monitoring Well No.	Distance From CH-1 to Monitoring Well (feet)	Drawdown Measured After 400 Minutes (inches H_2O)
CH-1	179.8	0.52
P-1S	175.8	0.48
CH-2	177.1	0.60
P-2M	174.8	0.70
CH-3	158.6	0.80
P-3S	161.2	0.79
P-4S	3.6	5.50
CH-5	215.0	0.0

Note: Drawdown is used here as a measure of the difference between atmospheric conditions and the vacuum measured in the aerifer.

Table B-6
Summary of Air Permeability Test at Extraction Well CH-5

Date: 1/13/93
Duration: ≈350 minutes (13:45 to 17:35)
Flow: 100 acfm
Drawdown (at extraction well): 44.2 inches H_2O

Monitoring Well No.	Distance From CH-1 to Monitoring Well (feet)	Drawdown Measured After 350 Minutes (inches H_2O)
CH-1	234.0	0.33
P-1S	232.5	0.25
CH-2	282.0	0.10
P-2M	281.0	1.10
CH-3	302.1	0.13
P-3S	304.5	0.16
CH-4	215.0	0.37
P-4S	218.5	0.35

Note: Drawdown is used here as a measure of the difference between atmospheric conditions and the vacuum measured in the aerifer.

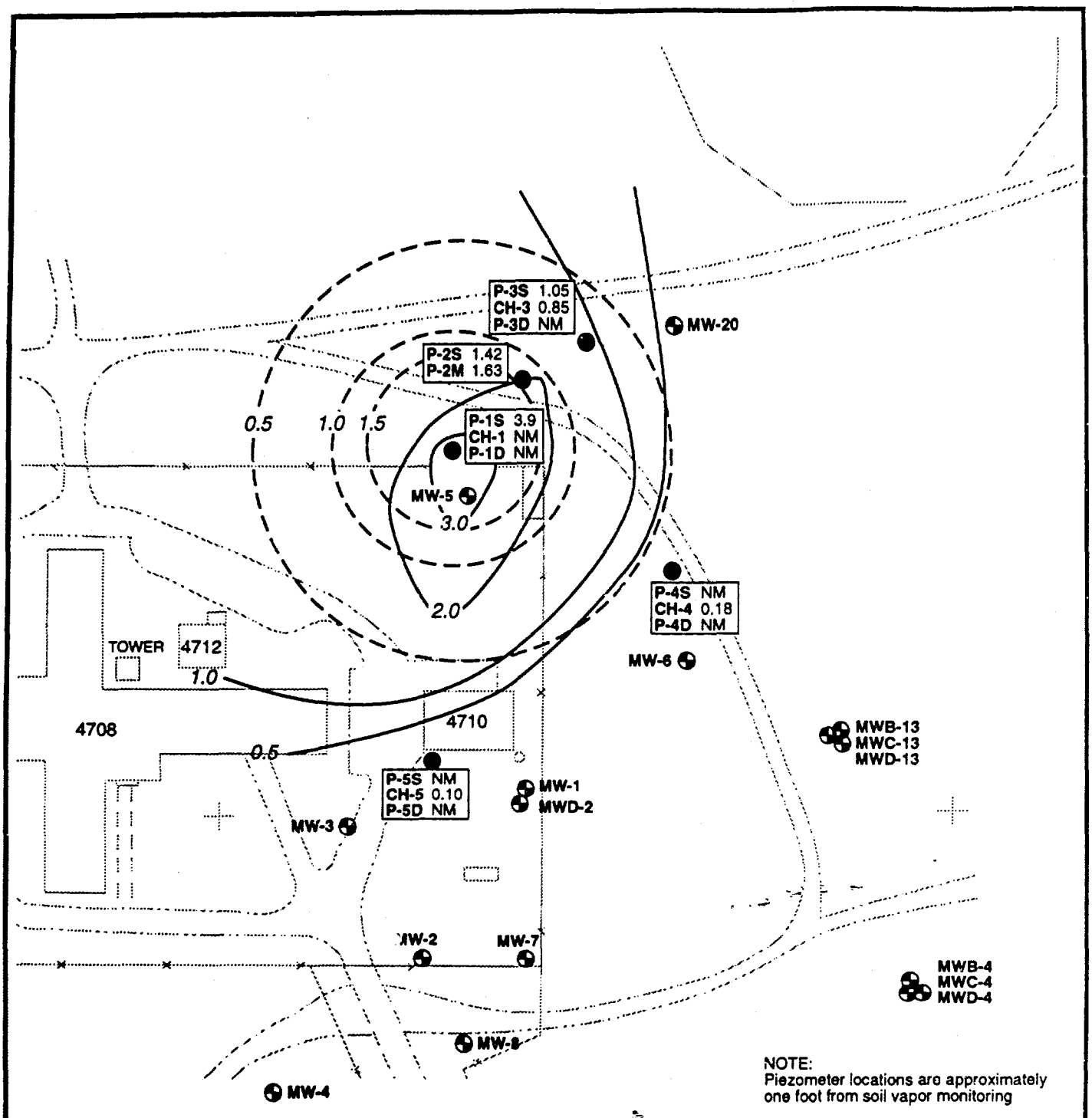
The drawdown surrounding each of the extraction wells near the conclusion of the tests is shown on Figures B-4 through B-6. These plots of the actually measured drawdown are useful for showing the quasi-steady-state area of influence of the extraction wells. However, in order to model the flow of gas in the vadose zone for

designing an efficient multiple well extraction system, the properties of the aerifers must be quantified.

On the basis of the preliminary observation of the test data, it was decided to fit the test data to an analytical model of flow in multiple aquifers (Hemker, 1987) based on the assumptions of Massmann, 1989. (Massmann assumes that existing models for groundwater flow in saturated porous media can be used to model flow of air in unsaturated porous media given appropriate corrections for fluid viscosity and density.) A copy of Massmann is included at the back of this technical memorandum as Attachment B-2. The assumptions included in this model are summarized in Table B-7.

Table B-7
Assumptions and Limitations in Applying Groundwater Flow Models for Evaluation of Gas Flow in the Vadose Zone (after Massmann, 1989)

Assumption	Limitation
The equation of motion for gas transport can be approximated using an equation similar to Darcy's Law.	In fine-grained materials, Darcy's Law underestimates discharge by neglecting slip flow; however, assumption is likely a valid approximation for flow in sands and gravels.
Effects of diffusional flow are negligible.	Valid assumption for predicting pressure distributions.
Vapor behaves as ideal gas.	Valid approximation for temperature and pressure conditions typical of vapor extraction systems.
There is constant and uniform porosity.	Porosity will generally vary with time and with location due to natural variations in geologic materials and due to temporal and spatial variations in moisture content.
Gravitational effects are negligible.	Valid assumption for vapor extraction applications.
Compressibility of the porous medium is negligible.	Valid assumption because the compressibility of the porous medium is small compared to the compressibility of the vapor.
Gas transport can be modeled using the equation for incompressible flow.	Valid assumption for pressure variation on order of one-half an atmosphere and less.
Molecular weight is uniform.	Molecular weight will vary with gas composition; variations will generally be small for typical applications of methane control and organic vapor recovery.



NOTE:
Piezometer locations are approximately one foot from soil vapor monitoring

LEGEND

- SOIL VAPOR MONITORING WELL
- P-1S 1.42 / CH-1 1.63 — DRAWDOWN MEASURED IN SHALLOW PIEZOMETER (inches H_2O) / DRAWDOWN MEASURED IN MODERATE DEPTH WELL OR PIEZOMETER (inches H_2O)
- NA — NOT APPLICABLE
- NM — NOT MEASURED
- MW-1 — EXISTING B-C AQUIFER GROUNDWATER MONITORING WELL
- 1.0 — — — CALCULATED DRAWDOWN USING TEST PARAMETERS (inches H_2O)
- 1.0 ——— ACTUAL DRAWDOWN BASED ON SHALLOW AND MODERATE DEPTH WELL OR PIEZOMETER (inches H_2O)

N

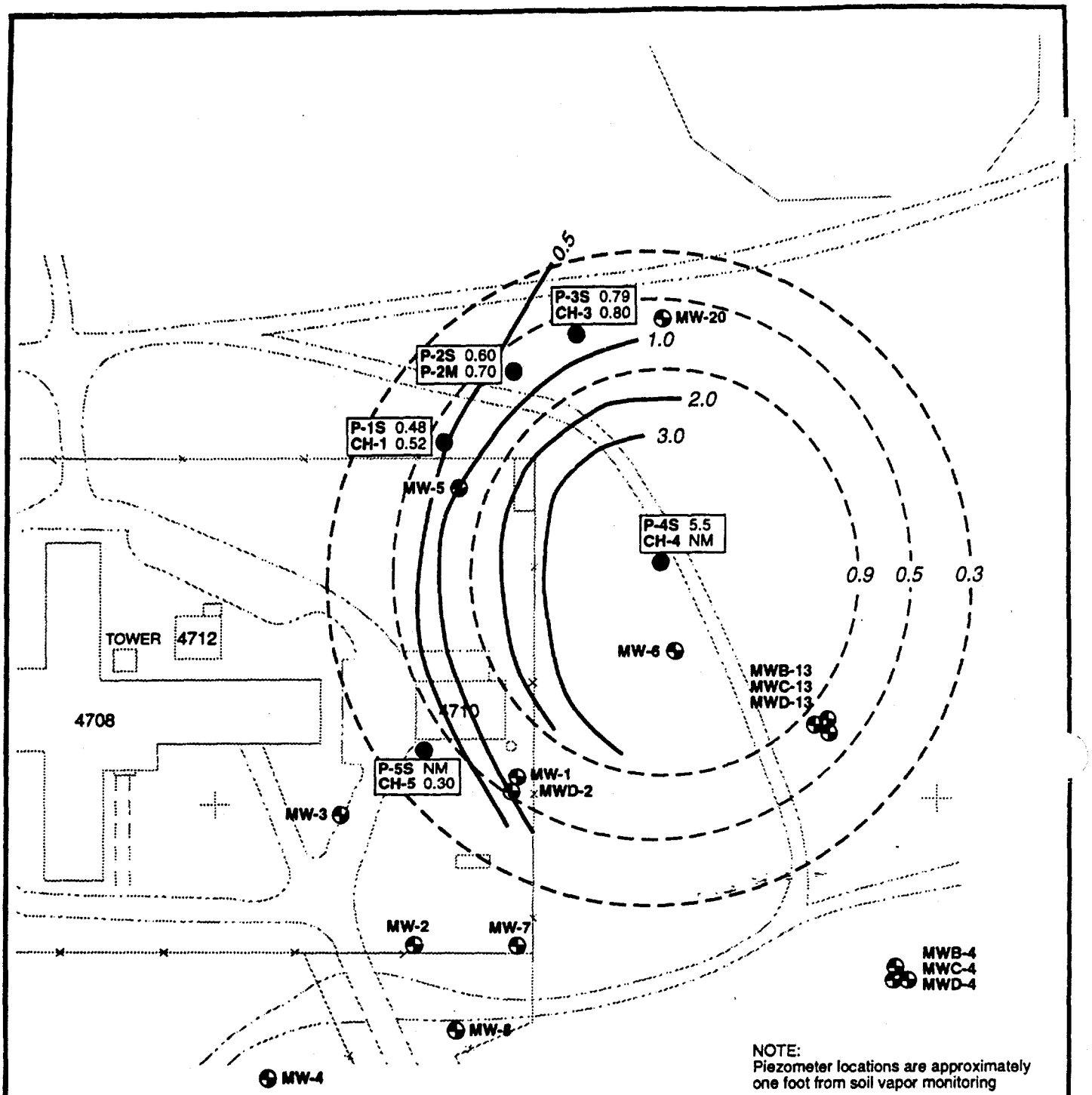
SCALE (Approximate)
0 100 FEET

FIGURE B-4
CONTOURS FOR AIR PERMEABILITY EXTRACTION TEST AT CH-1

DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412_246
9066.19



NOTE:
Piezometer locations are approximately one foot from soil vapor monitoring

LEGEND

●	SOIL VAPOR MONITORING WELL
P-1S 1.42	DRAWDOWN MEASURED IN SHALLOW PIEZOMETER (inches H_2O)
CH-1 1.63	DRAWDOWN MEASURED IN MODERATE DEPTH WELL OR PIEZOMETER (inches H_2O)
NA	NOT APPLICABLE
NM	NOT MEASURED
MW-1 ⊕	EXISTING B-C AQUIFER GROUNDWATER MONITORING WELL
1.0 – – –	CALCULATED DRAWDOWN USING TEST PARAMETERS (inches H_2O)
1.0 ———	ACTUAL DRAWDOWN BASED ON SHALLOW AND MODERATE DEPTH WELL OR PIEZOMETER (inches H_2O)

SCALE (Approximate)
0 100 FEET

FIGURE B-5
CONTOURS FOR AIR PERMEABILITY EXTRACTION TEST AT CH-4
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412_347
9066.19

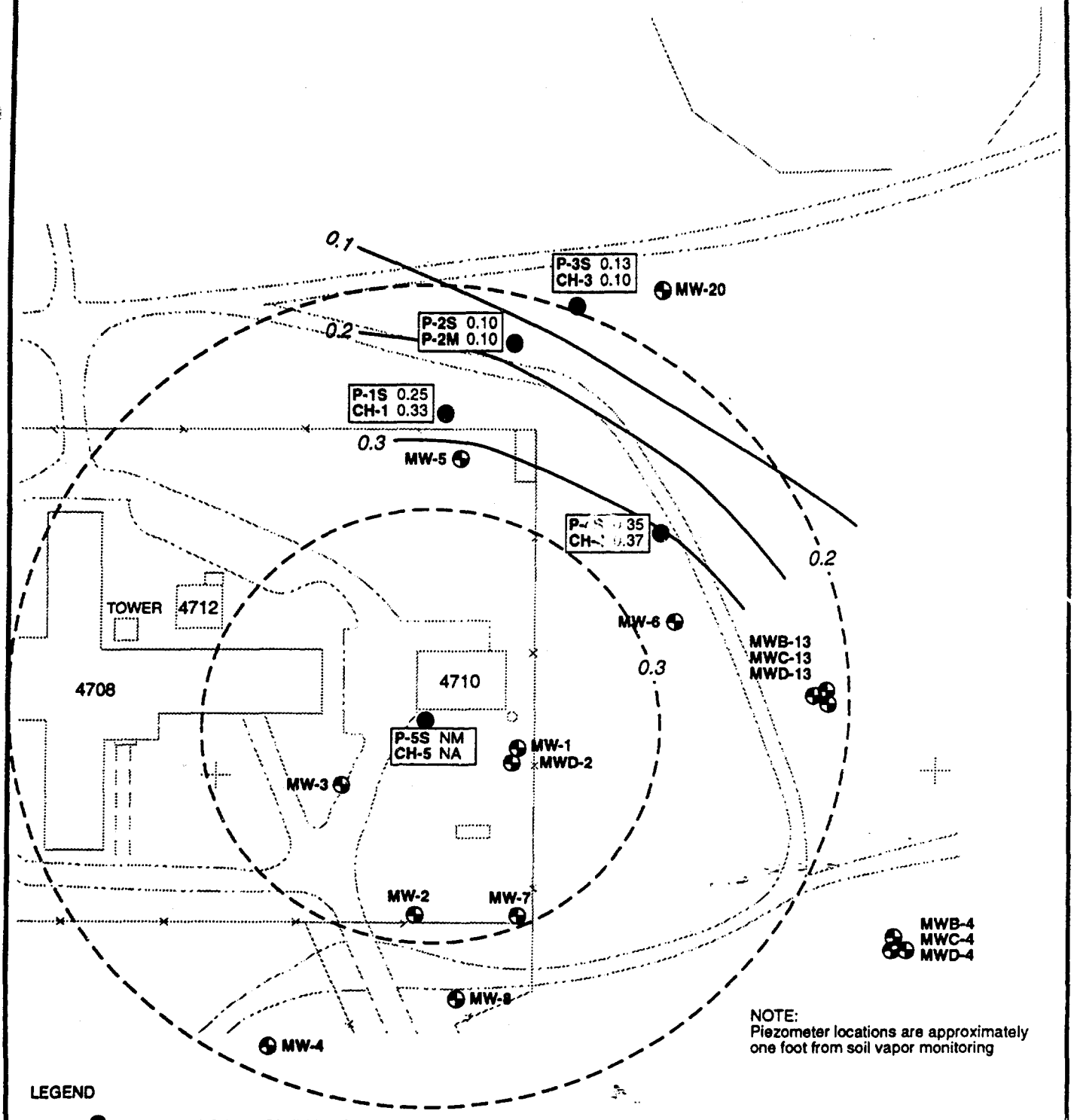


FIGURE B-6
CONTOURS FOR AIR PERMEABILITY EXTRACTION TEST AT CH-5
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412_248
5085.19

The model describes the transient flow of fluid in "n" aerifers and n+1 aeritards, taking into account storage in both the aerifers and aeritards. Based on examination of the stratigraphy, the application and multiple aerifer flow model for the Davis Site included two aerifers and three aeritards. A multiple aerifer system that includes n aerifers and n+1 aeritards requires (4n+2) parameter values (aerifer transmissivity, aerifer storativity, aeritard storativity, and aeritard conductance) to describe the transient response of the aerifer system to pumping. For the Davis Site, this means that as many as 10 parameters would need to be defined. Traditional curves matching approaches to aquifer testing are appropriate for estimating only two or three parameters. Therefore, a computer-based technique for test evaluation is appropriate to evaluate this test (Kruseman and de Ridder, 1991).

The approach used in the interpretation of these data is outlined below.

- Develop a conceptual model of the hydrogeologic system at the site including stratigraphic units and boundary conditions.

  The hydrogeologic system at the Davis Site consists of complexly interlayered aquifers and aquitards of varying thicknesses and lateral continuity. The interpretation of test data collected from vadose zone systems of this type typically requires the use of a methodology that can account for leakage between aerifers and drawdown in one aerifer in response to pumping in an adjacent aerifer. Based on the stratigraphy observed in drilling at the site, the vadose zone existing at the time of testing was subdivided into two aerifers and three aeritards. The upper boundary of the modeled domain was assumed to be at a constant pressure.

- Starting from reasonable parameter estimates for aerifer transmissivity and aeritard vertical resistance, an iterative procedure was used to improve the fit between observed and calculated drawdown values by adjusting the unknown parameter values.

  The method chosen to obtain parameter estimates from the observed drawdown data is a computer program known as MLU (Hemker, 1992; Hemker and Maas, 1987). MLU is a transient, multiaquifer simulation that uses a least squares, curve-fitting algorithm to calculate aquifer and aquitard parameters (Aquifer Transmissivity (T), Aquifer Storage Coefficient (S), Aquitard Resistance (R), and Aquitard Storage Coefficient (S')) based on time-drawdown data collected during aquifer tests. The solution technique accounts for both leakage between aquifers and storage of water in the aquitards and aquifers. Any number of parameters can be fixed, based on prior knowledge of their approximate values, and the program estimates the values of the remaining parameters.

MLU is an analytical model for the flow of groundwater in the unsaturated zone. However, the conditions that occurred during the air conductivity testing at the Davis Site appear to meet the assumptions described in Table B-8. For example, the maximum drawdown in the tests was only on the order of 0.1 atmosphere.

- When adjustments to the parameter values during the iterative process become sufficiently small as to not significantly improve the fit, the iterative process is stopped.

- As a check on the accuracy of the parameter values, the observed drawdown values are compared with drawdown data calculated using the parameter values (see Figures B-4 through B-6). However, it must always be remembered that there are a number of combinations of parameter values that could yield a good fit with the observed data.

Test Evaluation

The test data for Wells CH-1 and CH-4 were evaluated using MLU. The results of that analysis are shown on Table B-8.

Table B-8
Results of Air Conductivity Testing

Vadose Zone Property	CH-1	CH-4	CH-5
Air transmissivity of the upper permeable zone (ft^2/day)	200	120	340
Air transmissivity of the lower permeable zone that was pumped (ft^2/day)	3.8	4.9	
Vertical Resistance of the upper confining layer (day)	77	200	2900
Vertical Resistance of the middle confining layer (day)	35	1.9	
Storativity of the upper permeable zone (unitless)	0.00004 (assumed)	0.00004 (assumed)	0.00004 (assumed)
Storativity of the lower permeable zone (unitless)	0.00008 (assumed)	0.00008 (assumed)	

The test of Well CH-5 yielded results that were not readily evaluated using a two-aerifer model. The test began when there was a positive pressure in the vadose zone. Since this was the last test to be run, one possibility is that the air in the vadose zone was trapped beneath a downward-moving wetting front of low air permeability so the vadose zone air could not readily escape. In essence, the wet surface soils acted as a temporary cap over the area that increased the area of influence over

what may typically occur when the soils are dry. Another reason that the CH-5 test could not be readily evaluated was that all the monitoring wells were located 200 feet from the pumping well. At those distances from the pumping well at the fringe of the cone of depression, each aerifer would act similarly, so there is little information that could be used to quantify the properties of a two-aerifer system. Therefore, the CH-5 test was evaluated using a single-layer model.

Based on the single-layer evaluation of the CH-5 test, the transmissivity results are similar to that derived for the two-layer model. The vertical resistance of the surface soils measured during the CH-5 test is about one order-of-magnitude higher, consistent with the hypothesis that a low conductivity wetting front had infiltrated the surface during the test.

Discussion of the Results

The air permeability test at the Davis Site yielded adequate results for estimating the properties of the aerifers and aeritards at the site that can be used to help design a soil vapor extraction system. However, it must always be kept in mind that the conductivity to air moving in the vadose zone is sensitive to the moisture content in the vadose zone. As the pores become wetter, the conductivity to air will decrease. Conversely, as the pores become drier, the permeability to air will increase. At the present time, there are no site-specific data that could be used to quantify the relationship between moisture content and the air conductivity.

Recommendations

Air permeability results were used as input data for modeling of airflow in the vadose zone at the Davis Site. A discussion of the air modeling and SVE requirements are presented in Appendix I. Refer to Appendix I for details on the design and operation of the proposed SVE system. Using the results generated from the air permeability testing, the following recommendations have been formulated:

- The five existing SVMW can be used as SVE wells during operation of an SVE system. Flow rates up to 100 scfm can be applied to the existing 2-inch wells.
- At this time, no additional SVE wells are needed for an SVE system.
- If additional SVE wells are needed for soil vapor capture, the wells should be no smaller than 4 inches in diameter.
- Additional air permeability testing during the dry season may result in different air permeability values because of differing antecedent moisture conditions.

Works Cited

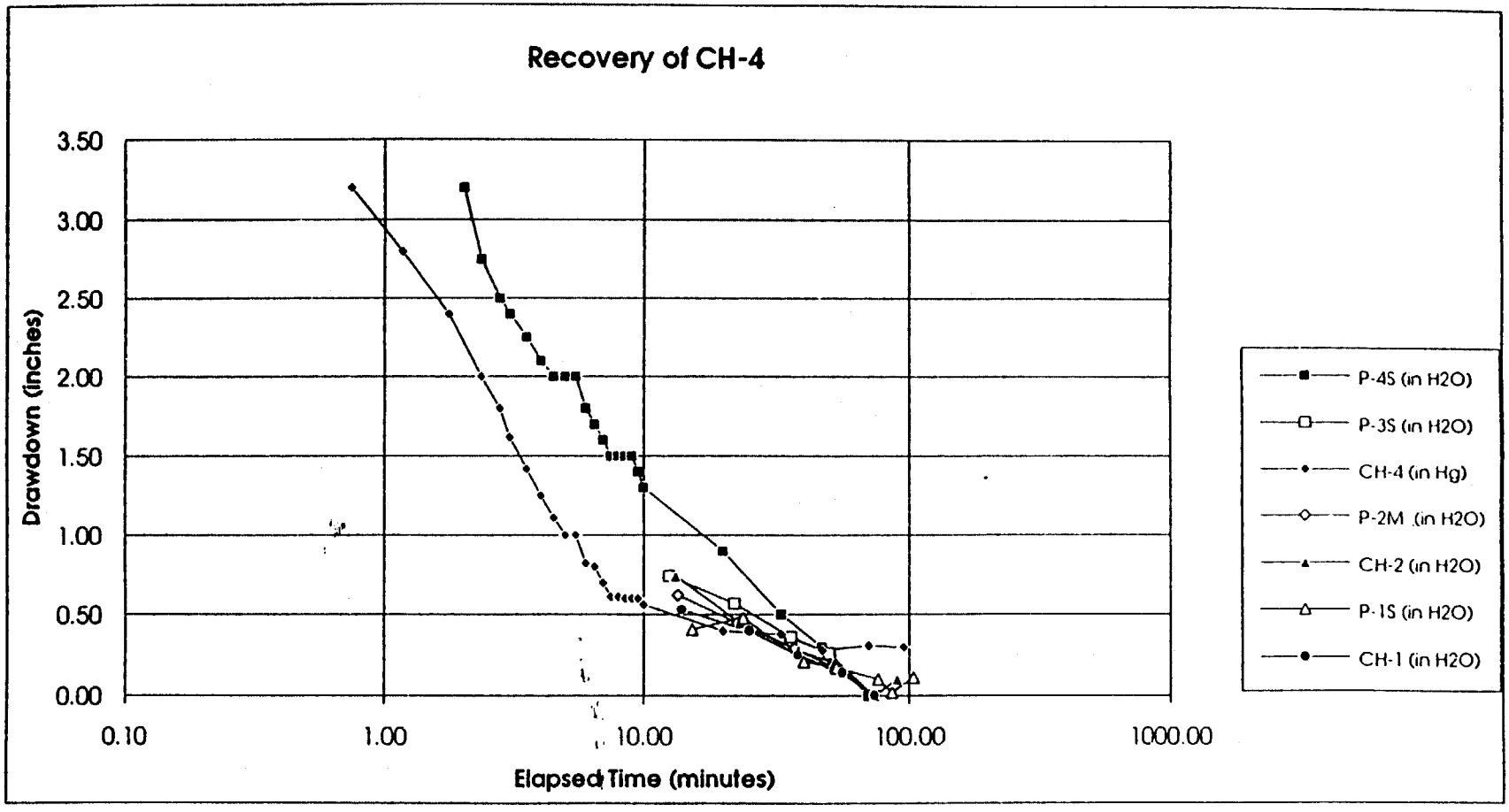
Hemker, C. J., and C. Maas. 1987. "Unsteady Flow to Wells in Layered and Fissured Aquifer Systems." *Journal of Hydrology.*

Hemker, C. J. 1992. *MLU: Microcomputer Aquifer Test Analysis for Unsteady-State Flow in Multiple-Aquifer Systems, Version 2.03.* May.

Kruseman, G. P. and N A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data.*

Massmann, J. W. 1989. "Applying Groundwater Flow Models in Vapor Extraction System Design." *Journal of Environmental Engineering.* Vol. 115, No. 1. February.

Attachment B-1


Recovery of CH-4
Drawdown (inches)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.10
1.00
10.00
100.00
1000.00
Elapsed Time (minutes)
P-4S (in H2O)
P-3S (in H2O)
CH-4 (in Hg)
P-2M (in H2O)
CH-2 (in H2O)
P-1S (in H2O)
CH-1 (in H2O)

Attachment B-2

Φ = transformation function;
μ_c = Marquardt parameter;
ρ_b = apparent adsorbent density (M/L^3);
σ^2 = standard deviation;
∂ = partial derivative;
∂^2 = second partial derivative;
$( )^T$ = transpose of a matrix;
$( )^{-1}$ = inverse of a matrix;
$\int$ = integration;
Σ = summation; and
0 = zero vector.

Subscripts:

r = derivative with respect to r;
rr = second order derivative with respect to r;
t = derivative with respect to t.

Applying Groundwater Flow Models in Vapor Extraction System Design

By J. W. Massmann,[1] Associate Member, ASCE

Abstract: Vapor extraction systems have recently been used in a variety of environmental engineering applications, including controlling methane migration and remediating problems associated with spills of volatile and semi-volatile organic compounds. The differential equations that govern pressure flow of gas and vapor in soil are nonlinear in that gas density depends upon gas pressure. However, if the maximum pressure difference between any two points in the flow field is less than approximately 0.5 atmospheres, the differential equations developed to model groundwater flow provide good approximations to gas transport. Vapor extraction systems generally operate under pressure differences on the order of 0.2 atmospheres. Analytical and numerical groundwater flow models can therefore be used to model vapor and gas transport if the proper set of input variables is defined. Analytical groundwater flow models are used to evaluate the results of a field gas extraction test. The results of these evaluations indicate groundwater models can provide an efficient and readily-accessible tool to aid in designing vapor extraction systems.

Introduction

Several recent environmental concerns have caused an increase in the use of shallow vapor extraction systems. Included in these concerns are the generation and migration of methane gas from landfills and the migration of vapors from spills of petroleum products and other volatile and semi-volatile organic compounds. Methane gas, which is generated within landfills by the bacterial decomposition of organic materials, can migrate through unsaturated soils for distances of hundreds of meters. Although methane is nontoxic, it presents an explosion hazard when mixed with air at concentrations between 5 and 15% by volume. One of the most effective methods to control methane migration is by pumping the methane out of the ground with vapor extraction systems (e.g., Emcon, 1980).

The second principal application of vapor extraction systems is to clean soils contaminated with volatile and semi-volatile organic compounds as a result of leaking underground tanks, pipelines, and other accidental spills. These compounds may be present in the unsaturated zone in both liquid and vapor phases. The liquid portion generally cannot be directly extracted from the unsaturated soils. However, applying a vacuum to the soil will cause the volatile vapors to be removed. As the vapors are extracted, more liquid will vaporize and will be removed from the soil. This application of vapor extraction systems has proven very effective in a number of situations, e.g., Wootan and Voynick (1984), Crow et al. (1985).

A typical vapor extraction system consists of a gas pump or blower connected to a series of wells that have been completed in unsaturated soil. The vacuum from the pump causes gas to flow through the soil to the extraction

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wells. The extraction rates are usually quite low, generally on the order of 15–150 L/s (30–300 cu ft/min) for each extraction well. Pressure drops within the extraction wells are typically less than 7,000 Pascals (30 in. of water or 1 lb/sq in.). Air-injection wells are sometimes used in conjunction with the extraction wells to further control gas flow. Depending upon the application, gas treatment equipment such as carbon adsorption beds may be required before the vapors can be discharged into the atmosphere.

Vapor extraction systems are generally designed using an empirical and site-specific approach. Prototypes or pilot-scale systems are often constructed at each site to determine system parameters such as well depths, well spacings, and extraction rates. One of the reasons that the design process has been primarily empirical is that readily accessible analytical tools have not been available to practicing professionals.

During the same time period that applications of vapor extraction systems have increased, the popularity of prepackaged groundwater flow models has also increased. These models may range from relatively simple analytical models to more complex finite-element or finite-difference numerical models. With a few exceptions, the physical processes on which vapor extraction systems are based are very similar to the physical processes on which groundwater pumping systems are based. It seems natural, then, that groundwater flow models could play a role in the design of vapor extraction systems.

The objective of this paper is to present a methodology for using groundwater flow models as an aid in the design of gas extraction systems. The goal is to obtain approximate results that can be used to infer design parameters. The emphasis of the presentation is on describing methods to predict the number of injection and extraction wells, and the injection and extraction rates, required to obtain a specified pressure drawdown throughout a prescribed zone of influence. This information is required to select blowers and pumps, manifold diameters, and well geometries. Rigorous methods for predicting vapor composition are not included in the development. This information would be required to select vapor treatment equipment if treatment were necessary. Predicting the zones of influence and the sensitivities of these zones to system configurations is of fundamental importance in vapor system design. Predicting time-varying vapor compositions is a more tenuous task and is arguably of secondary importance in many applications.

Although the analytical methods discussed are approximate, they are relatively easy to complete and may result in significant savings in extraction system design. Care has been taken in preparing the paper so that simplifying assumptions are explicitly identified and the limitations that they present are discussed.

Darcy's Law and Gas Transport in Porous Media

The flow of gases and vapors through porous media is treated in a relatively extensive literature, including texts by Satterfield (1970), Geankoplis (1972), and Dullien (1979). The presentation in this section, based in part on the developments by Collins (1961) and Dullien (1979), is intended to illustrate the similarities and differences between the equation of motion for gas flow and the equation of motion for groundwater flow.

The transport of gas or vapor through porous media results from both

pressure and concentration gradients. As stated above, the primary objective is to predict drawdowns in gas pressures caused by extraction systems, rather than to predict gas compositions. Neglecting diffusional flow due to concentration gradients will not have an appreciable impact on gas pressure predictions.

The flow of gases due to pressure gradients differs from the flow of liquids in that the velocity at the pore walls cannot generally be assumed to be zero for gas transport (Dullien 1979). Darcy's law, which governs the flow of liquids in porous media, is based on viscous flow in which the molecular velocity is zero along pore walls. Nonzero velocities at the pore wall will result in greater flow than predicted by Darcy's law. The additional flow is termed "slip flow" or "drift flow." Dullien (1979) presents an expression for the pressure flow of gases that includes the effects of both viscous flow and slip flow:

$$F = -\left(\frac{r^2 p}{8\mu} + \frac{4rRT}{3W_m V_m}\right)\frac{1}{RT}\nabla P \quad \ldots\ldots (1)$$

where F = molar flux (mole/L^2/T); r = average pore radius (L); P = gas pressure (M/L/T^2); μ = gas viscosity (M/L/T); R = gas constant (L^2/degree K/T^2/mole); T = gas temperature (degree K); W_m = molecular weight (M/mole); and V_m = mean molecular velocity (L/T).

The first term on the right side of Eq. 1 accounts for viscous flow and the second term accounts for slip flow. Slip flow is proportional to the average pore radius, whereas viscous or Darcy flow is proportional to the average pore radius squared. The importance of slip flow increases as the average pore radius decreases and as the pressure decreases. The relative importance of slip flow and viscous flow for gas composition, pressure, and temperature conditions typical of vapor extraction systems is illustrated on Fig. 1. For pore radii greater than approximately 10^{-3} mm (4×10^{-5} in.), the effects of slip flow are small relative to viscous flow. Silt and clay materials will have pore radii of this magnitude. Sand and gravel materials will have pore radii on the order of 10^{-1} mm (4×10^{-3} in.) and greater.

The magnitude of viscous flow relative to the slip flow for transport in silt, sand, and gravel materials indicates that the equation of motion for gas flow in these types of materials should be of the same form as the equation of motion for groundwater flow, which is given by Darcy's law:

$$q = \frac{-k\rho}{\mu}\nabla\phi \quad \ldots\ldots (2)$$

where q = specific discharge (L/T); k = permeability of the soil (L^2); μ = viscosity of the fluid (M/L/T); ρ = density of the fluid (M/L^3); and ϕ = fluid potential (L^2/T^2). The fluid potential for a compressible fluid is given by

$$\phi = gZ + \int_{P_0}^{P}\frac{dP}{\rho} \quad \ldots\ldots (3)$$

where P = pressure of the fluid (M/L/T^2); Z = elevation (L); and g = gravitational acceleration (L^2/T).

A number of assumptions are required to get Eq. 1 in a form similar to

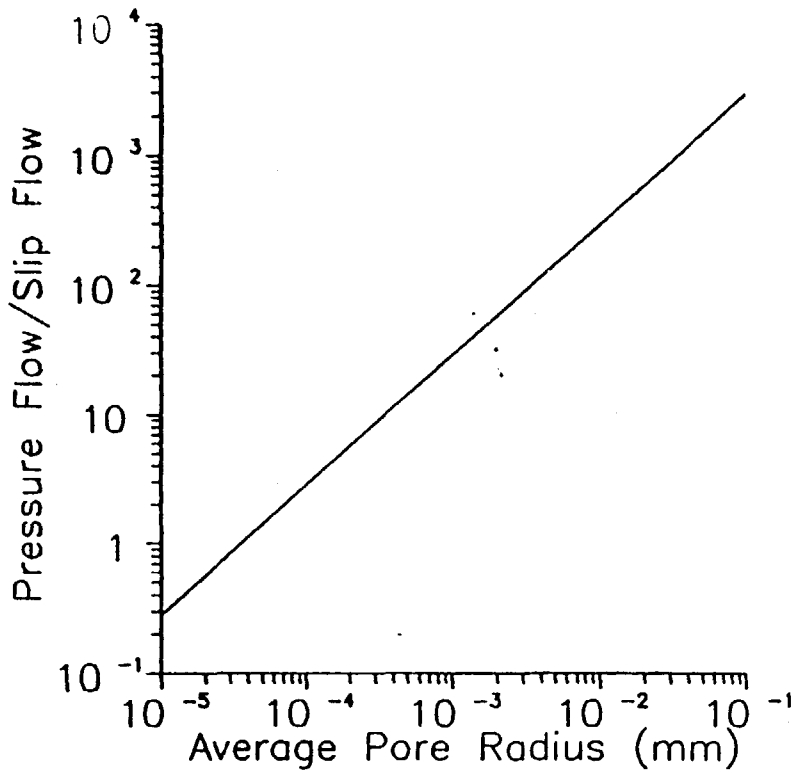

FIG. 1. The Relative Importance of Pressure and Slip Flow for Conditions Typical of Vapor Extraction Systems

Darcy's law. The first assumption is that slip flow can be neglected for flow in sand and gravel materials. Experiments performed by Alzaydi and Moore (1978) show that if pressure gradients typical to those used for vapor extraction systems are imposed across columns containing Ottawa sand, the discharge of air through the samples becomes a linear function of the pressure gradient within a short period of time, as predicted by Darcy's law. These same experiments performed on columns containing kaolinite clay show similar behavior, although more time is required to achieve linear pressure gradients. Their results support the evidence presented on Fig. 1 that Darcy's law provides a good approximation for gas flow in sands and gravels and a fair approximation for flow in silts, clays, and other low-permeability materials.

The second step in relating Darcy's law to gas transport involves expressing volume flux q in terms of molar flux F. The relationship between the two is given by

$$q = \frac{W_m F}{\rho} \quad \ldots\ldots (4)$$

The driving force for flow in Darcy's law is potential gradient, whereas the driving force in the gas transport equation is pressure gradient. An equation of state relating gas density as a function of gas pressure and temperature is required to convert from potentials to pressures. For the pressures and temperatures used in vapor extraction systems, the gas can be modeled as an ideal gas dependent only upon pressure. The relationship between pressure and density for an ideal gas is given by the Boyle-Mariotte law (Collins 1961):

$$\rho = \frac{W_m P}{RT} \quad \ldots\ldots (5)$$

Eqs. 3 and 5 can be combined to obtain an expression for fluid potential as a function of pressure:

$$\phi = gZ + \frac{RT}{W_m}\int_{P_0}^{P}\frac{dP}{P} \quad \ldots\ldots (6a)$$

$$\phi = gZ + \frac{RT}{W_m}\ln\left(\frac{P}{P_0}\right) \quad \ldots\ldots (6b)$$

The gradient in potential is given by

$$\nabla\phi = g\nabla Z + \frac{RT}{PW_m}\nabla P \quad \ldots\ldots (7)$$

The second term on the right side of Eq. 7 is generally much greater than the first term for vapor extraction system applications. The potential gradient can therefore be approximated by

$$\nabla\phi = \frac{RT\nabla P}{PW_m} = \frac{\nabla P}{\rho} \quad \ldots\ldots (8)$$

For many groundwater applications, fluid potential is converted to hydraulic head using the relationship

$$\nabla h = \frac{\nabla\phi}{g} = \frac{\nabla P}{\rho g} \quad \ldots\ldots (9)$$

Combining Eqs. 2 and 8 gives Darcy's law in terms of pressure gradient:

$$q = \frac{-k\rho\nabla P}{\mu\rho} = \frac{-k}{\mu}\nabla P \quad \ldots\ldots (10)$$

Finally, combining Eqs. 1, 4, and 10 and neglecting slip flow gives Darcy's law in terms of the gas transport coefficient:

$$q = \frac{-k}{\mu}\nabla P = \frac{W_m F}{\rho} = \frac{-r^2 W_m P}{\rho 8RT\mu}\nabla P = \frac{-r^2}{8\mu}\nabla P \quad \ldots\ldots (11)$$

Eq. 11 shows that the relationship between the Darcy coefficient of permeability and the Dullien coefficient for viscous gas transport is given by

$$k = \frac{r^2}{8} \quad \ldots\ldots (12)$$

Gas Transport Equations and Simplifying Assumptions

Three general equations are required to model pressure drawdowns caused by vapor extraction systems. These are: (1) A continuity equation; (2) an equation of motion; and (3) an equation of state. The continuity equation is given by

$$\frac{\partial(np)}{\partial t} = -\nabla(pq) \quad \ldots\ldots (13)$$

where n = porosity of the soil (dimensionless).

As discussed in the previous section, the equation of motion for gas transport can be approximated using the form of Darcy's law given by Eq. 11. The equation of state relating gas density to pressure and temperature is given by Eq. 5, which is based on ideal gas behavior. Eqs. 5, 11, and 13 can be combined to obtain a general transport equation for the transient flow of gas in soils. This equation is of the form

$$\frac{\partial(np)}{\partial t} = \nabla\left(\frac{pk}{\mu}\nabla P\right) \quad \ldots\ldots (14)$$

A number of simplifying assumptions can be made to get Eq. 14 to look like the groundwater flow equation that is solved by most models. The first assumption that can be made is an outgrowth of the assumption of ideal gas behavior. In most groundwater flow models, the left-hand side of Eq. 14 is given by Freeze and Cherry (1979):

$$\frac{\partial(np)}{\partial t} = \frac{S_s}{g}\frac{\partial P}{\partial t} \quad \ldots\ldots (15)$$

where S_s = specific storage (L^{-1}).

The term on the left side of Eq. 15 can be expanded using the chain rule to give

$$\frac{\partial(np)}{\partial t} = \frac{n\partial p}{\partial t} + \frac{p\partial n}{\partial t} \quad \ldots\ldots (16)$$

The second term on the right is negligible compared to the first and can be dropped. Combining Eq. (16) with Eq. 5 gives

$$\frac{\partial(np)}{\partial t} = \frac{n\partial p}{\partial t} = \frac{nW_m}{RT}\frac{\partial P}{\partial t} \quad \ldots\ldots (17)$$

A comparison of Eqs. 15 and 17 shows that the specific storage term for transport of an ideal gas is given by

$$S_s = \frac{gnW_m}{RT} \quad \ldots\ldots (18)$$

Eqs. 14, 15, and 18 can be combined to give that equation for transient flow of an ideal gas in a porous media:

$$S_s\frac{\partial P}{\partial t} = \nabla\left(\frac{pgk}{\mu}\nabla P\right) \quad \ldots\ldots (19)$$

TABLE 1. Summary of Assumptions and Limitations

Assumption (1)	Limitations (2)
The equation of motion for gas transport can be approximated using equation similar to Darcy's law	In fine-grained materials, Darcy's law underestimates discharge by neglecting slip flow; however, assumption is likely valid approximation for flow in sands and gravels
Effects of diffusional flow are negligible	Valid assumption for predicting pressure distributions
Vapor behaves as ideal gas	Valid approximation for temperature and pressure conditions typical of vapor extraction systems
Constant and uniform porosity	Porosity will generally vary with time and with location due to natural variations in geologic materials and due to temporal and spatial variations in moisture content
Molecular weight is uniform	Molecular weight will vary with gas composition; variations will generally be small for typical applications of methane control and organic vapor recovery
Gravitational effects are negligible	Valid assumption for vapor extraction applications
Compressibility of the porous media is negligible	Valid assumption for essentially is small as compared to all systems; compressibility the vapor
Gas transport can be modeled using the equation for incompressible flow	Valid assumption for pressure variations on order of one-half an atmosphere and less

This equation compares to the equation for transient flow of groundwater (Freeze and Cherry 1979):

$$S_s\frac{\partial h}{\partial t} = \nabla(K\nabla h) \quad \ldots\ldots (20)$$

where K = hydraulic conductivity (L/T).

A summary of the assumptions used to develop a gas transport equation that is in the same form as the groundwater flow equation is presented in Table 1. A brief description of the limitations imposed by these assumptions is also included in Table 1.

The fundamental difference between Eqs. 19 and 20 is that Eq. 19 is nonlinear because of the dependence of gas density on gas pressure. In a strict sense, this nonlinearity does not allow computer models developed to solve the groundwater flow equation to be used to model gas transport. Some type of linearization is required before this can occur. An analytical solution to Eq. 19 for one-dimensional flow in a semi-infinite and homogeneous medium (Kidder 1957) can be used to select this linearization. The equation that Kidder solves is

$$D_1\frac{\partial P}{\partial t} = \frac{\partial}{\partial x}\left(P\frac{\partial P}{\partial x}\right) \quad \ldots\ldots (21)$$

TABLE 2. Comparison of Exact and Approximate Solutions to Eq. 21

Y	Exact solution (2)	Eq. 24 Value (3)	Eq. 24 Error (4)	Eq. 25 Value (5)	Eq. 25 Error (6)
		(a) P_i/P_o = 0.90			
0.00000	0.90000	0.90000	0.00%	0.90000	0.00%
0.10000	0.91201	0.91179	0.02%	0.91125	0.08%
0.20000	0.92360	0.92321	0.04%	0.92227	0.14%
0.40000	0.94475	0.94414	0.06%	0.94284	0.20%
0.80000	0.97571	0.97519	0.05%	0.97421	0.15%
2.00000	0.99957	0.99956	0.00%	0.99953	0.00%
		(b) P_i/P_o = 0.80			
0.00000	0.80000	0.80000	0.00%	0.80000	0.00%
0.10000	0.82580	0.82492	0.11%	0.82249	0.40%
0.20000	0.85024	0.84863	0.19%	0.84454	0.67%
0.40000	0.89361	0.89119	0.27%	0.88568	0.89%
0.80000	0.95442	0.95245	0.21%	0.94842	0.63%
2.00000	0.99921	0.99916	0.00%	0.99906	0.01%
		(c) P_i/P_o = 0.50			
0.00000	0.50000	0.50000	0.00%	0.50000	0.00%
0.10000	0.58433	0.57823	1.04%	0.55623	4.81%
0.20000	0.63594	0.64577	1.55%	0.61135	6.80%
0.40000	0.76928	0.75584	1.75%	0.71420	7.16%
0.80000	0.90761	0.89810	1.05%	0.87105	4.03%
2.00000	0.99846	0.99824	0.02%	0.99766	0.08%
		(d) P_i/P_o = 0.20			
0.00000	0.20000	0.20000	0.00%	0.20000	0.00%
0.10000	0.40031	0.38466	3.91%	0.28997	27.56%
0.20000	0.52597	0.50378	4.22%	0.37816	28.10%
0.40000	0.69742	0.67175	3.68%	0.54271	22.18%
0.80000	0.88395	0.86742	1.87%	0.79368	10.21%
2.00000	0.99811	0.99775	0.04%	0.99626	0.19%

where $D_i = n\mu/k$.

Eq. 21 is of the same form and has the same terms as Eq. 19. The boundary and initial conditions that Kidder assumes are as follows: $P(x,0) = P_o$ for all x greater than zero; and $P(0,t) = P_i$ for all t greater than zero. The solution to Eq. 21 for several values of P_i/P_o is presented in Table 2. The dimensionless variable Y used to present the solution is given by

$$Y = \sqrt{\frac{D_i}{P_o}}\frac{x}{2\sqrt{t}} \quad \ldots\ldots (22)$$

Kidder also developed an approximate solution to Eq. 21. This approximation is of the form

$$\frac{P^2 - P_i^2}{P_o^2 - P_i^2} = erf(Y) \quad \ldots\ldots (23)$$

where $erf(Y)$ is the error function of Y.

A comparison of the approximate and exact solutions to Eq. 21 is presented in Table 2 for several values of P_i/P_o. The difference between the two is less than one percent for all values of Y if P_i/P_o is greater than 0.8 and is less than five percent if P_i/P_o is greater than 0.2. Kidder notes that Eq. 23 is the exact solution to the following linear differential equation:

$$\frac{\partial P^2}{\partial t} = \frac{P_o}{D_i}\frac{\partial^2(P^2)}{\partial x^2} \quad \ldots\ldots (24)$$

Kidder showed that the values of P/P_o obtained using Eq. 24 differ by less than five percent from the more accurate values obtained using Eq. 21 for all values of P_i/P_o. The largest discrepancy occurs in the extreme case in which P_i/P_o approaches zero. Pressure differences in vapor extraction systems are typically on the order of 10–20% (P_i/P_o = 0.8–0.9). Given these relatively small pressure differentials, a second approximation to Eq. 21 can be given by

$$\frac{\partial P}{\partial t} = \frac{P_o}{D_i}\frac{\partial^2 P}{\partial x^2} \quad \ldots\ldots (25)$$

Eq. 25 is a linear differential equation with P as the dependent variable, whereas P^2 is the dependent variable in Eq. 24. The solution to Eq. 25 has the same form as Eq. 23, only written in terms of P instead of P^2. Solutions to Eq. 25 for several values of P_i/P_o are included in Table 2. The difference between the exact solution for compressible flow (Eq. 21) and the solution to Eq. 25 is less than one percent for all values of Y if P_i/P_o is greater than 0.8. However, the approximation becomes quite poor as P_i/P_o drops below 0.5.

Because the solution to Eq. 25 is very close to the solution of Eq. 21 for P_i/P_o greater than 0.8, it follows that the linear differential equation given by 25 is a close approximation of the nonlinear equation given by 21 for vapor extraction applications. This allows us to rewrite Eq. 19, the equation for gas transport in porous media, as a linear differential equation of the form

$$S_r\frac{\partial P}{\partial t} = \nabla\left(\frac{\rho_o g k}{\mu}\nabla P\right) \quad \ldots\ldots (26)$$

where ρ_o is the initial gas density.

Eq. 26 is now in the same form as the groundwater flow equation, Eq. 20, with pressure, P, replacing hydraulic head, h, and initial gas conductivity replacing hydraulic conductivity. All the models developed to evaluate groundwater flow can be applied to vapor extraction systems if these replacements are made.

Methods for Estimating Input Parameters and Boundary Conditions

The six input parameters required to model vapor transport using Eq. 26 are the viscosity, initial density, temperature, and molecular weight of the gas, and the porosity and permeability of the porous media. Methods to

TABLE 3. Approximate Viscosities for Typical Gas Components in Vapor Extraction Systems (Weast 1968)

Gas or vapor (1)	Viscosity (Micropoise) 30° C (2)	40° C (3)
Air	180	190
Carbon dioxide	148	157
Ethane	90	96
Ethylene	100	106
Methane	108	114
Nitrogen	174	182

Note: 1 micropoise is equal to 1×10^{-6} g/cm/s.

estimate each of these parameters and typical values for vapor extraction systems are discussed below.

Gas Viscosity

The viscosity of a gas mixture is a function of composition and can be estimated using formulas presented by Geankoplis (1972) and Dullien (1979). For most gas mixtures associated with vapor extraction systems, a simple composition-weighted average of viscosities gives a good approximation:

$$\mu_{mix} = \sum_{i=1}^{m} X_i \mu_i \quad \ldots\ldots (27)$$

where X_i = mole fraction of component i; μ_{mix} = viscosity of gas mixture; μ_i = viscosity of component i; m = number of gas components in the mixture. Viscosities for typical components of concern in methane and organic vapor recovery systems are listed in Table 3.

Gas Density

The initial density of an ideal gas varies inversely with pressure, and varies with molecular composition. Density variations due to changes in composition will depend upon site-specific gas compositions and can be estimated with Eq. 5. Densities for gas compositions typically encountered in vapor extraction system applications will generally vary from approximately 0.7 g/L (0.04 lb/cu ft) for 100% methane to approximately 1.3 g/L (0.08 lb/cu ft) for air with high concentrations of volatile organic vapors.

Molecular Weight

The molecular weight of a gas mixture is equal to the composition-weighted average of the molecular weights of the individual gas components:

$$W_m = \sum_{i=1}^{m} X_i (W_m)_i \quad \ldots\ldots (28)$$

where $(W_m)_i$ is the molecular weight of component i.

TABLE 4. Typical Permeability Values for Unconsolidated Geologic Materials (Freeze and Cherry 1979)

Geologic material (1)	Range of permeability (Darcies) (2)
Silt	10^{-3}–1
Silty sand	10^{-2}–10^{2}
Clean sand	10^{-1}–10^{3}
Gravel	10^{2}–10^{3}

Porosity

The porosity that should be used in the storage coefficient in Eqs. 18 and 26 is the fraction of the soil volume filled with vapor or gas. Because of the presence of moisture in the soil pores, the air porosity will generally be less than the total porosity. The relationship between air porosity and total porosity is given by

$$n_a = n_T(1 - S) \quad \ldots\ldots (29)$$

where n_a = air porosity; n_T = total porosity; and S = degree of saturation.

Permeability

Permeability is overwhelmingly the most uncertain and variable of the input parameters included in Eq. 26. Its value can range over more than 13 orders of magnitude, depending upon the type of geologic material and the presence of moisture. Most vapor extraction systems are installed in unconsolidated materials consisting of silts, sands, and gravels. Ranges of permeabilities for dry samples of these materials are summarized in Table 4.

Three general methods for estimating gas permeability are presented in this section. These are: (1) Estimating permeability as a function of saturated hydraulic conductivity; (2) estimating permeability as a function of grain size parameters; and (3) estimating permeability from gas extraction tests.

The relationship between saturated hydraulic conductivity and permeability is given by

$$K = \frac{\rho g k}{\mu} \quad \ldots\ldots (30)$$

Permeability is a function only of properties of the porous media, while hydraulic conductivity is a function of both porous media properties and fluid properties. For vapor extraction systems that will be operated in dry soils whose saturated hydraulic conductivities are known, Eq. 30 can be solved to obtain permeability by incorporating the viscosity and density of water. For hydraulic conductivities in centimeters per second and gas permeabilities in darcies (1 darcy = approximately 1×10^{-8} cm^2), the conversion is given by:

$$k = 1{,}040\,K \quad \ldots\ldots (31)$$

Gas permeability can also be estimated from grain size analyses performed on soil samples. Eq. 12 presents permeability as a function of pore radius:

$$k = 0.125r^2 \quad \ldots\ldots (32)$$

where permeability k and pore radius r are in units of L^2. For k in darcies and r in millimeters, Eq. 32 can be rewritten as

$$k = 125{,}000r^2 \quad (33)$$

Relationships have been developed to estimate the average pore radius of sands and gravels from the results of grain size analyses. These estimates, which should be viewed as order-of-magnitude approximations, are generally of the form

$$r = cD_{15} \quad (34)$$

where c = empirical constant; and D_{15} = grain size for which 15% by weight of particles are smaller. Sherard et al. (1984) have found that a c value of 0.1 gives reasonable approximations for sand and gravel soils.

Combining Eqs. 33 and 34 gives an expression for gas permeability as a function of the grain size parameter:

$$k = 1{,}250D_{15}^2 \quad (35)$$

where the permeability, k, is in darcies and the grain size parameter, D_{15}, is in millimeters. It should be emphasized that the permeability value predicted by Eq. 35 is a gross approximation that should be viewed as an order-of-magnitude estimate, at best.

The third general method for estimating gas permeability is from data collected during gas extraction tests. Curve-fitting techniques similar to the Theis, Jacob, and Hantush methods that are used to evaluate groundwater pumping tests can also be used to evaluate these extraction tests. The general procedure for performing extraction tests is to attach a vacuum pump to an extraction well completed in unsaturated soils and to measure pressure drawdowns in adjacent gas probes as a function of time. A plot of pressure drawdown versus time can be used to estimate "gas conductivity" in an approach directly analogous to groundwater pumping tests. Gas permeability can then be estimated from the gas conductivity by incorporating the viscosity and density of gas into Eq. 30. This procedure is presented in more detail in the section describing the case history.

The estimated values for the viscosity, initial density, temperature, and molecular weight of the gas, and the porosity and permeability of the porous media, can be directly incorporated into groundwater flow models to evaluate conceptual designs for vapor extraction systems. A summary of the method is as follows:

1. Estimate gas viscosity using Eq. 27. If no information is available regarding gas composition, assume a viscosity of air equal to 1.8×10^{-4} g/cm/s (0.018 centipoise).
2. Estimate initial gas density based on vapor composition. If no information is available regarding composition, assume a density of air equal to 1.3×10^{-3} g/cm^3 (1.3 g/L).
3. Estimate permeability using either Eqs. 30, 31, or 35. Convert into units of cm^2 by using the conversion of 1 darcy equals 1×10^{-8} cm^2.
4. Calculate a "gas conductivity" using Eq. 30 and the viscosity, initial density, and permeability from items 1–3. Use a gravitational constant equal to 980 cm/s^2. The resulting gas conductivity will be in units of cm/s.

5. Estimate the molecular weight of the gas mixture using Eq. 28. If no information is available regarding gas composition, assume a molecular weight of air equal to 28 g/mole.
6. Estimate a storage coefficient using Eq. 18. Use the molecular weight from item 5, the gravitational constant from item 4, and the porosity from Eq. 29. Use a value of RT equal to 2.5×10^{10} cm^{2}g/s^{2}mole. The resulting storage coefficient will be in units of cm^{-1}.

The storage coefficient and gas conductivity can be directly incorporated into groundwater flow models. The only other items that need to be addressed are boundary conditions. Prescribed flow boundaries and impermeable boundaries are directly analogous to groundwater flow conditions: one simply specifies flow rates in units of length cubed per time (e.g., cm^3/s). Prescribed head boundaries need to be replaced with prescribed pressure boundaries.

Case History: Midway Landfill, Kent, Washington

A case history is presented in this section to further illustrate the methodology for using groundwater flow models to evaluate the design of vapor extraction systems. The motivation for including the case history is to illustrate the details of the approach. The presentation is divided into two parts. In the first part, the Theis solution for groundwater flow is used to develop a preliminary design for a gas extraction well. In the second part, the results of field extraction tests are analyzed and the effectiveness of the gas extraction well is evaluated.

The case history is based on the Midway Landfill in Kent, Washington. The landfill is located in an abandoned gravel quarry just south of Seattle. A generalized cross section through the landfill is illustrated on Fig. 2 [Hart-Crowser (1986)]. The site stratigraphy can be summarized as a three-layer system. The top layer consists of low-permeability glacial till. This till overlies a thick deposit of sand and gravel. Beneath the sand and gravel is a layer of clay and clayey-silt. The approximate location of the groundwater table is at the top of the clay unit.

Methane gas produced by the decomposition of organic materials within the landfill had been detected in the immediate vicinity of the landfill at concentrations above the lower explosive limit. An extensive gas monitoring program was undertaken in the fall and winter of 1985 by the Washington Department of Ecology (WDOE) and the City of Seattle to evaluate the extent of methane migration. The program involved installing and monitoring more than 80 subsurface gas probes and monitoring gas concentrations in homes and businesses in the vicinity of the landfill. These activities indicated that potentially explosive conditions were present over distances greater than 500 m from the landfill site. The most extensive migration occurred to the east of the landfill. Homes and business were evacuated in response to these potentially explosive conditions, some for periods in excess of several months.

Two general activities to alleviate the problems associated with the methane migration were undertaken in late 1985 and early 1986. The first activity was to install a methane collection system on the landfill to prevent additional gas from leaving the site. This on-site system was intended to stop the gas source but not to clean areas in which gas had previously migrated.

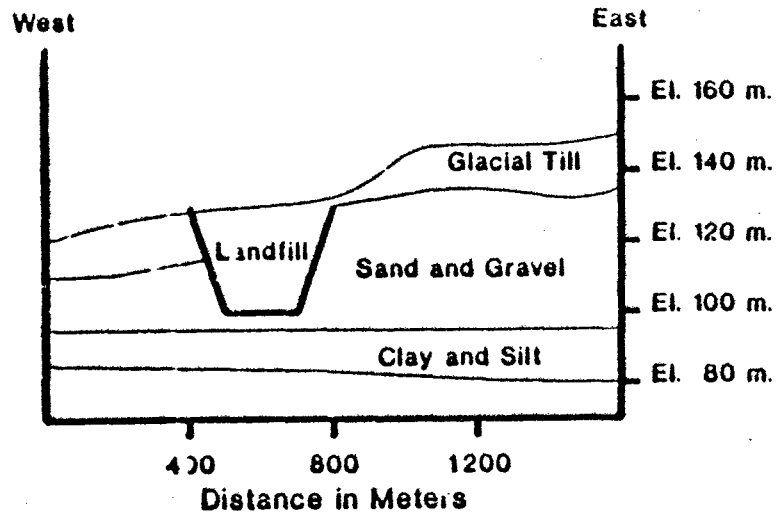

FIG. 2. Generalized Geologic Cross Section Through Midway Landfill

The second activity was to install several off-site extraction wells east of the landfill to reduce the methane concentrations in these areas. Groundwater flow models were used to help evaluate the design of both the on-site and off-site methane control systems. The evaluations pertaining to the off-site system are described below.

Preliminary Design of Off-Site Extraction Wells

The WDOE decided to install several off-site extraction wells in the neighborhoods east of the landfill in an effort to reduce methane concentrations in the vicinities of homes that had been evacuated. The approach adopted by the WDOE was to extract the methane by using a relatively small number of large extraction wells. The off-site wells were to be completed in the sand and gravel formation immediately beneath the surface till and were to be approximately 100 ft deep.

Extraction systems were available that were capable of delivering 115 L/s of gas (250 cu ft/min) when operating against a vacuum equal to approximately 1 m of water (0.1 atmosphere). The Theis solution for groundwater flow was used to predict pressure drawdowns within the extraction well as a function of extraction rate to determine if these systems would be suitable for the Midway site. The steps included in this evaluation are summarized below:

1. Gas viscosity. Monitoring activities had indicated that the subsurface gas composition near the proposed site for the extraction well was approximately 50% methane and 50% air, by volume. The viscosity of methane is 1.1×10^{-4} g/cm/s and the viscosity of air is 1.8×10^{-4} g/cm/s. The viscosity for the gas

TABLE 5. Predicted Pressure Drawdowns Within Extraction Well as Function of Time for Extraction Rate Equal to 115 L/s

Time after start-up (1)	Pressure drawdown (cm of water) (2)
10 min	43
100 min	52
1,000 min	62
7 days	71
70 days	80

mixture is given by Eq. 27: $\mu_{mix} = 0.5(1.1 \times 10^{-4}) + 0.5(1.8 \times 10^{-4}) = 1.45 \times 10^{-4}$ g/cm/s.

2. Gas density. The density of methane is approximately 0.7×10^{-3} g/cm^3 and the density of air is approximately 1.3×10^{-3} g/cm^3. The resulting density of the gas mixture is therefore 1.0×10^{-3} g/cm^3.

3. Permeability. Soil samples collected at the time the gas monitoring probes were installed were available for grain size analyses. The average D_{15} grain size from 47 samples collected from the sand and gravel formation was approximately 0.1 mm. Incorporating this value into Eq. 35 gives an order-of-magnitude estimate for permeability equal to 10 darcies (1×10^{-7} cm^2).

4. Gas conductivity. The gas conductivity can be estimated using Eq. 30: $K = \rho g k/\mu = 1 \times 10^{-3}(980)1. \times 10^{-7}/(1.45 \times 10^{-4}) = 7 \times 10^{-4}$ cm/s.

5. Molecular weight. The molecular weights for methane and air are 16 g/mole and 28 g/mole, respectively. The molecular weight for the mixture is given by Eq. 28: $W_m = 0.5(16) + 0.5(28) = 22$ g/mole.

6. Storage coefficient. The storage coefficient, assuming a value for porosity equal to 0.15, is given by Eq. 18: $S_s = gnW_m/RT = 0.15(980)22/(2.5 \times 10^{10}) = 1.3 \times 10^{-7}$ cm^{-1}.

The gas conductivity and storage coefficient values can be directly incorporated in the Theis equation to estimate pressure drawdowns:

$$h - h_0 = \frac{Q}{4\pi K b} W(u) = \frac{QW(u)}{4(3.14)(0.0007)(2{,}500)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (36)$$

where b = the thickness of the unsaturated zone (L); Q = volumetric flow rate (L^3/T); $W(u)$ = well function (dimensionless); $h - h_0$ = drawdown (L); and $u = r^2 S_s/4Kt$.

The drawdowns calculated with Eq. 36 will be in centimeters of gas. To convert to equivalent centimeters of water, it is necessary to multiply the calculated drawdown by the specific gravity of the gas, which is approximately 0.001 for a gas density of 1×10^{-3} g/cm^3. Estimated pressure drawdowns within a 15-cm diameter extraction well operating at an extraction rate of 115 L/s (250 cu ft/min) are presented in Table 5. After 70 days of pumping, the estimated drawdown within the extraction well is approximately 80 equivalent cm of water. This estimate suggested that the extraction system capable of delivering 120 L/s against 1 m of vacuum would be suitable for the Midway site.

Evaluation of Field Extraction Tests

An extraction well was installed east of the Midway Landfill in January 1986. The construction of the well, based in a part on the preliminary design evaluations described above, is illustrated on Fig. 3. A pumping test was performed on the extraction well in February 1986 to evaluate the overall performance of the system. The test involved measuring the pressure drawdowns in the extraction well and in nearby observation probes as a function of time while the extraction well was pumped at a constant rate.

The pressures within the well were measured with a mercury manometer. The construction of the extraction well allows the pressures to be measured at the bottom of the well and at the ground surface. The pressure at the bottom of the well during the test was approximately −100 cm of water and the pressure at the top was approximately −95 cm of water (negative values denote vacuum). The extraction rate during the test, which was estimated by measuring the velocity within the header pipe at the ground surface, fluctuated between 100 and 110 L/s (215–235 cu ft/min). The gas temperature was 11° C (52° F).

The cluster of observation probes, which is illustrated on Fig. 3, contains shallow, intermediate, and deep probes. The pressures within the probes were measured with an electronic pressure transducer. The transducer provides continuous digital readings accurate to about 0.05 cm of water. The majority of the pressure measurements were made in the intermediate probe, which is screened between the depths of 40 and 60 ft. The measurements were

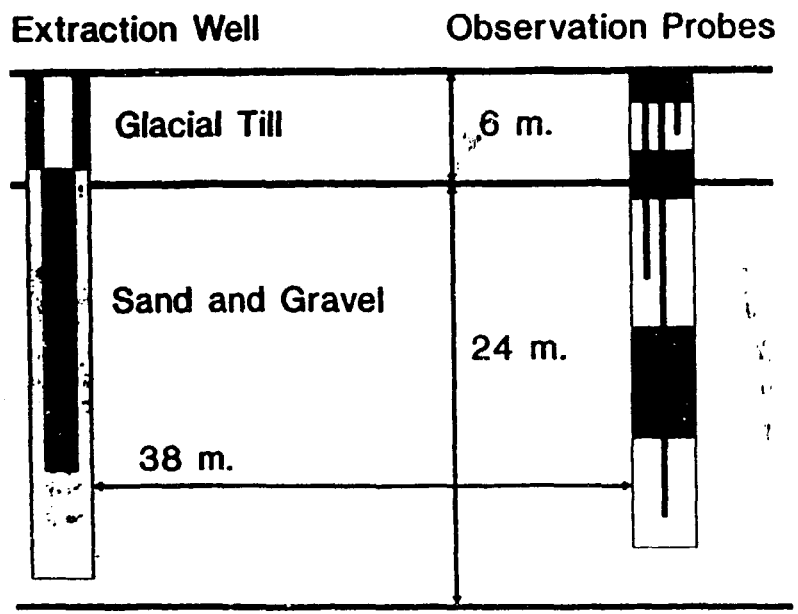

FIG. 3. Geometry of Extraction Well and Gas Probes used in Field Extraction Test

TABLE 6. Summary of Field Test Data and Evaluations; All Pressures and Drawdowns are in Equivalent Centimeters of Water

Time (min.) (1)	Observed pressure (2)	Corrected pressure (3)	Corrected drawdown (4)	Calculated drawdown (5)
0	−7.37	−7.37	0.00	0.00
1	−7.29	−7.42	0.05	0.00
2	−7.26	−7.45	0.08	0.00
3	−7.26	−7.42	0.05	0.02
5	−7.32	−7.40	0.03	0.15
6	−7.44	−7.55	0.18	0.25
7	−7.62	−7.75	0.38	0.43
9	−7.87	−8.03	0.66	0.74
11	−8.20	−8.39	1.02	1.04
14	−8.74	−8.97	1.60	1.52
18	−9.35	−9.66	2.29	2.16
21	−9.86	−10.19	2.82	2.60
26	−10.36	−10.80	3.43	3.22
31	−10.92	−11.43	4.06	3.81
41	−11.76	−12.42	5.05	4.82
46	−12.07	−12.81	5.44	5.23
61	−12.90	−13.90	6.53	6.35
101	−13.69	−15.32	7.95	8.00
166	−14.07	−16.74	9.37	9.14
306	−13.82	−17.48	10.11	10.16

made for approximately five hours. The observed pressures within the intermediate probe are listed in Table 6 and are illustrated on Fig. 4. The shallow probe, which is screened in the silty-sand confining materials, responded more slowly than the intermediate probe. The slower response is expected because of the lower permeability of the materials in which it is completed. The deep probe responded as quickly as the intermediate, but the total drawdown during the test was about 10% less than the drawdown in the intermediate probe. The smaller response of the deep probe may be due to its vertical position relative to the extraction well. The deep probe is completed below the bottom of the extraction well.

An important aspect of the extraction test is that pressures are measured relative to atmospheric pressure. Atmospheric pressure is seldom constant and therefore the observed drawdowns need to be corrected for variations in barometric pressures. During the 24 hours preceding the extraction test, the barometric pressures steadily increased by approximately 15 cm of water. The pressures steadily dropped by approximately 3 cm of water during the test.

Pressures were measured during the test in several gas probes outside the zone of influence of the extraction well to gain information on the effects of barometric pressures. As an example, Table 7 lists pressures in a gas probe approximately 150 m from the extraction well during the extraction test. This probe is screened over approximately the same depth as the intermediate observation probe shown on Fig. 3. The pressures within the probe clearly show the effects of variations in barometric pressure.

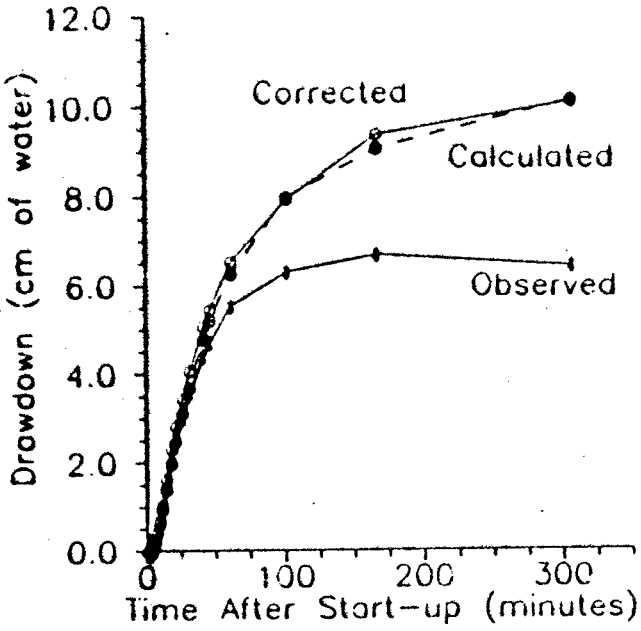

FIG. 4. Observed, Corrected, and Calculated Pressure Drawdowns for Fluid Extraction Test

The atmospheric high-pressure system that moved into the Midway area the day before the extraction test caused negative gauge pressures in the gas probes prior to pumping. Compensation can be made for these barometric effects by subtracting the gauge pressures that would be observed without pumping from the gauge pressures that were observed with pumping. The gauge pressures that would be observed without pumping can be predicted from measurements made in probes outside the extraction well's zone of influence. The corrections for barometric effects can be estimated by linearly interpolating the values in Table 7. This process results in the following corrections:

$$P_{cw} = P_{obs} - .016t \quad \text{for} \quad t < 150 \text{ minutes} \quad \ldots\ldots (37a)$$

TABLE 7. Gas Pressures Used to Correct for Barometric Effects—Probe GP-50 is Located 180 m from Extraction Well

Time after start of extraction test (min) (1)	Pressure in gas probe GP-50 (cm of water) (2)
0	−9.50
150	−7.11
300	−6.04

$$P_{cw} = P_{obs} - 2.4 - .007t \quad \text{for} \quad t > 150 \text{ minutes} \quad \ldots\ldots (37b)$$

where P_{cw} is the corrected pressure in equivalent centimeters of water and P_{obs} is the observed pressure in centimeters of water. Time $t = 0$ denotes the beginning of the test. The corrected pressures for the observation probe are included in Table 6 and Fig. 4.

A plot on logarithmic scales of the corrected drawdowns from Table 5 versus time indicates that the system responds as predicted by the Theis solution for the first 200 min of the test. The estimated gas conductivity from this portion of the test is 6.2×10^{-4} cm/s. This value was calculated using a match point of $W(u) = 1.2$; $u = 0.25$; $h - h_o = 5$ cm; and $t = 50$ min. The distance to the observation probe is 38 m (125 ft) and the extraction rate is 105 L/s (225 cu ft/min). In terms of permeability, this corresponds to a value of 9.2 darcies, which is remarkably close to the value of 12.5 darcies estimated from grain size analyses. The close correspondence is more likely an exception than a rule.

After 200 min, the observed drawdowns were less than the drawdowns predicted using the Theis solution. This discrepancy is likely due to leakage of air through the till confining unit shown on Fig. 3. The leaky-aquifer solution developed by Hantush (1956) can be used to incorporate the effects of air intrusion. The permeability of the confining unit can be estimated by matching the observed drawdowns with curves developed by Hantush (1956). A permeability of 0.2 darcies for the confining unit results a good fit to the data collected at the Midway site. The calculated drawdowns included in Table 6 and Fig. 4 are based on permeability for the confining unit equal to 0.2 darcies and permeability for the sand and gravel formation equal to 10 darcies. Except for the first three or four data points, the overall fit is quite good. It should be noted that the early data are close to the precision of the pressure transducer used to make the measurements.

The results of the extraction test were used to predict the performance of the extraction well over times and distances greater than those evaluated during the test. An analysis using the Hantush solution indicates that if the extraction well operates at 100 L/s, the steady-state drawdown at 150 m (500 ft) will be approximately 1 cm of water and steady-state conditions will be achieved after approximately 100 hours of pumping. These results, which were used to estimate a radius of influence for the well equal to 150 m, are based on the assumption that the geometric and material properties of the flow system determined during the pumping test can be extrapolated over an area much larger than actually tested. Boring logs from gas probes in the vicinity indicates that such an extrapolation is reasonable.

Conclusions

The conclusions that can be developed are summarized below:

1. The effects of slip flow are negligible for gas transport in silts, sands, and gravels under the pressure and temperature conditions typical of vapor extraction systems. An equation of motion with the same form as Darcy's law can therefore be used to model gas flow.

2. The differential equation governing gas transport in porous media is nonlinear because gas density is a function of gas pressure. However, if the differ-

ence in gas pressure between any two points in the flow field is less than approximately 0.2 atmospheres, the linear differential equation developed to model groundwater flow gives a good approximation when applied to gas flow. The approximation is within 1% of the exact solution under these pressure conditions. Most vapor extraction systems will operate in this range of pressures.

3. For pressure differences greater than approximately 0.5 atmospheres, the groundwater flow equation gives a poor approximation to the gas flow equation. A linear differential equation written in terms of gas pressure squared (Eq. 24) will still provide a good approximation to the nonlinear gas transport equation under these conditions.

4. The storage coefficient term for gas transport is a function of molecular weight, porosity, and temperature. It can be determined without relying upon field tests.

5. The results of the field extraction tests illustrate the importance of correcting field data for the effects of fluctuations in barometric pressures.

6. Data collected from field extraction tests can be analyzed in a manner analogous to groundwater pumping tests. Analytical solutions for modeling groundwater flow in confined and leaky aquifers give good approximations to gas flow phenomena.

Acknowledgments

The gas extraction tests described in the paper were completed while the author was a Project Engineer at Hart-Crowser, Inc., Seattle, Washington. The work was performed as part of a contract between Black and Veatch and the Washington Department of Ecology. Pete Kmet, an engineer with the Washington Department of Ecology, was instrumental in completing the extraction tests.

Appendix I. References

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Appendix II. Notation

The following symbols are used in this paper:

b = thickness of unsaturated zone (L);
c = empirical constant relating soil grain and pore sizes;
D_t = $\mu n/k$;
D_{15} = grain size parameter;
$erf(\ )$ = error function;
F = molar flux (mol/L²/T);
g = gravitational acceleration (L²/T);
h = fluid head (L);
h_o = initial fluid head (L);
K = hydraulic conductivity (L/T);
k = permeability of soil (L²);
m = number of gas components in mixture;
n = porosity of soil;
n_a = air porosity;
n_T = total porosity;
P = gas pressure (M/L/T²);
P_1 = gas pressure at extraction well or boundary (M/L/T²);
P_{cw} = pressures corrected for barometric effects (M/L/T²);
P_o = initial gas pressure (M/L/T²);
P_{obs} = observed gas pressure (M/L/T²);
Q = volumetric flow rate (L³/T);
q = specific discharge (L/T);
R = gas constant (L²/degree K/T²/mole);
r = average pore radius (L);
S = degree of saturation;
S_s = specific storage (L⁻¹);
T = gas temperature (degree K);
t = time;
u = dimensionless time used in Theis well function;
V_m = mean molecular velocity (L/T);
W_m = molecular weight (M/mol);
$(W_m)_i$ = molecular weight of component i;
$W(u)$ = Theis well function;
X_i = mol fraction of component i;
x = distance;
Y = $(D_t/P_o)(x/2t)$;
Z = elevation (L);
μ = gas viscosity (M/L/T);
μ_{mix} = viscosity of gas mixture (M/L/T);
μ_i = viscosity of component i (M/L/T);
ϕ = fluid potential (L²/T²);
ρ = density of the fluid (M/L³); and
ρ_o = the initial gas density (M/L³).

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Jim Thayer/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Treated Groundwater Reuse Soils Investigation
Davis Global Communications Site
Delivery Order 5055

PROJECT: SAC28722.55.12

Purpose and Scope

The purpose of this technical memorandum is to present the field and site testing data, laboratory analyses, and the overall site soil suitability evaluation for land application of treated groundwater on the Davis Global Communications Site (Davis Site) in Yolo County, California. The scope of this effort has been a feasibility-level investigation of the site soils to supplement information presented in the *Final Davis Global Communications Site Intermediate Remedial Design Report*, CH2M HILL, June 1993.

Background

The proposed 55-acre irrigation site is located in the northern half of the northeast quarter of Section 31, T11N R3E and bounded on the north by County Road 35 near the Yolo-Solano County line, southeast of the City of Davis. The Davis Site occupies approximately 316 acres in the eastern half of the section, and the entire site has native vegetation of annual grasses and forbs. The irrigation site is relatively flat with a minor natural drainageway paralleling the proposed irrigation area to the south. The surface drainage is to the southeast.

The site soils are described in the U.S. Department of Agriculture/Soil Conservation Service (USDA/SCS) Yolo County Soil Survey, June 1972. Two soil mapping units are defined within the irrigation site. The pertinent soil properties of the Marvin silty clay loam and the Brentwood silty clay loam soils are summarized in Table C(a)-1.

Table C(a)-1
Summary of Soil Properties[a]

Soil Mapping Unit	Soil Name	Slope (%)	Soil Textures		SCS Drainage Class	SCS Permeability Depth		CH2M HILL Suitability for Irrigation/ Restriction
			Surface	Subsoil		Surface/ Subsoil (in/hr)	Seasonal Water Table	
BrA	Brentwood silty clay loam	0 to 2	sicl	sil-sicl	Well	0.2 to 0.6/ 0.2 to 0.6	>5 feet	Suitable
Mf	Marvin silty clay loam	0 to 1	sicl	sic-sicl	Somewhat Poor	0.2 to 0.6/ 0.06 to 0.2	>5 feet	Marginal/Slow Infiltration

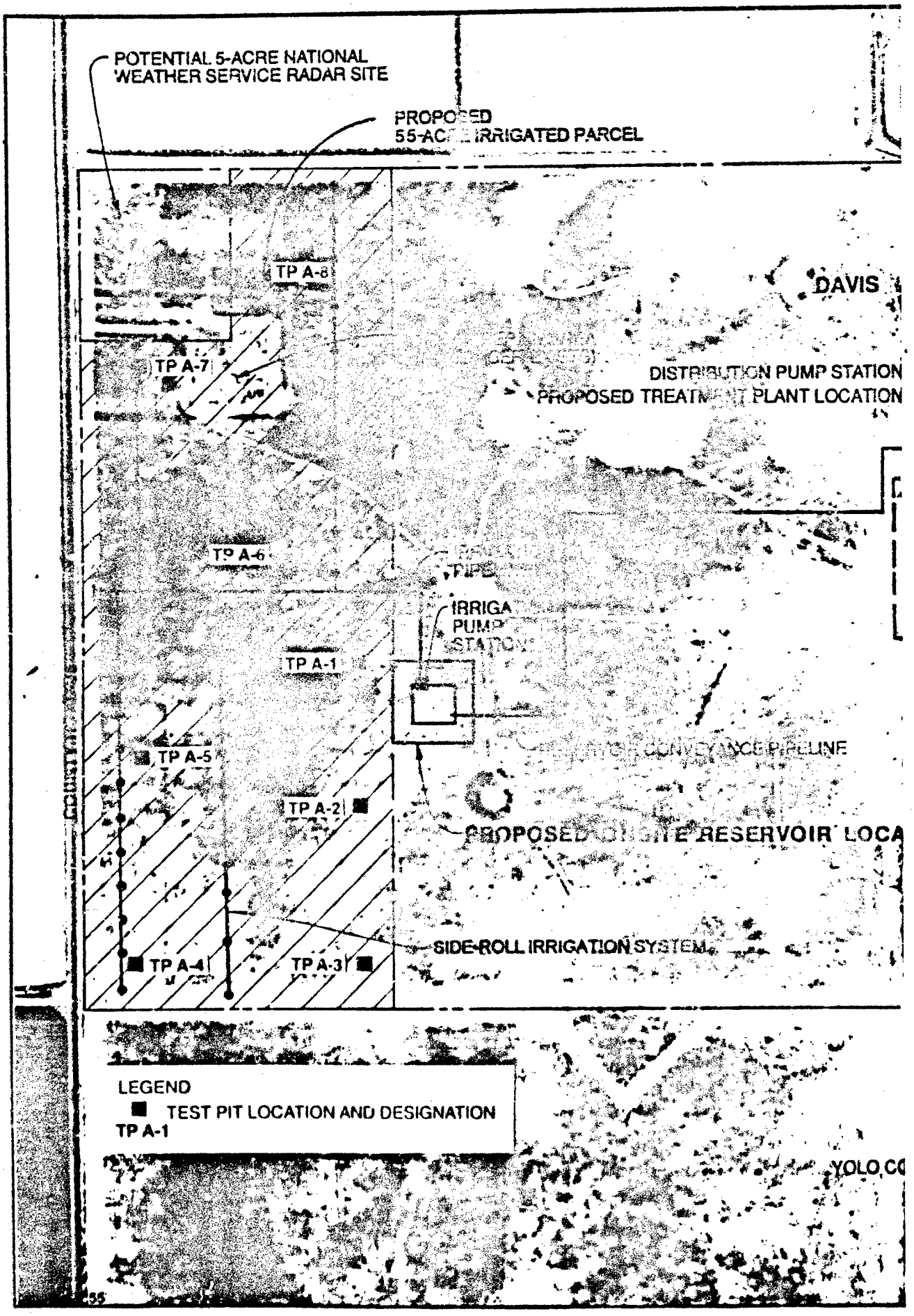
[a]Source: USDA/Soil Conservation Service, Yolo County Soil Survey, June 1992.

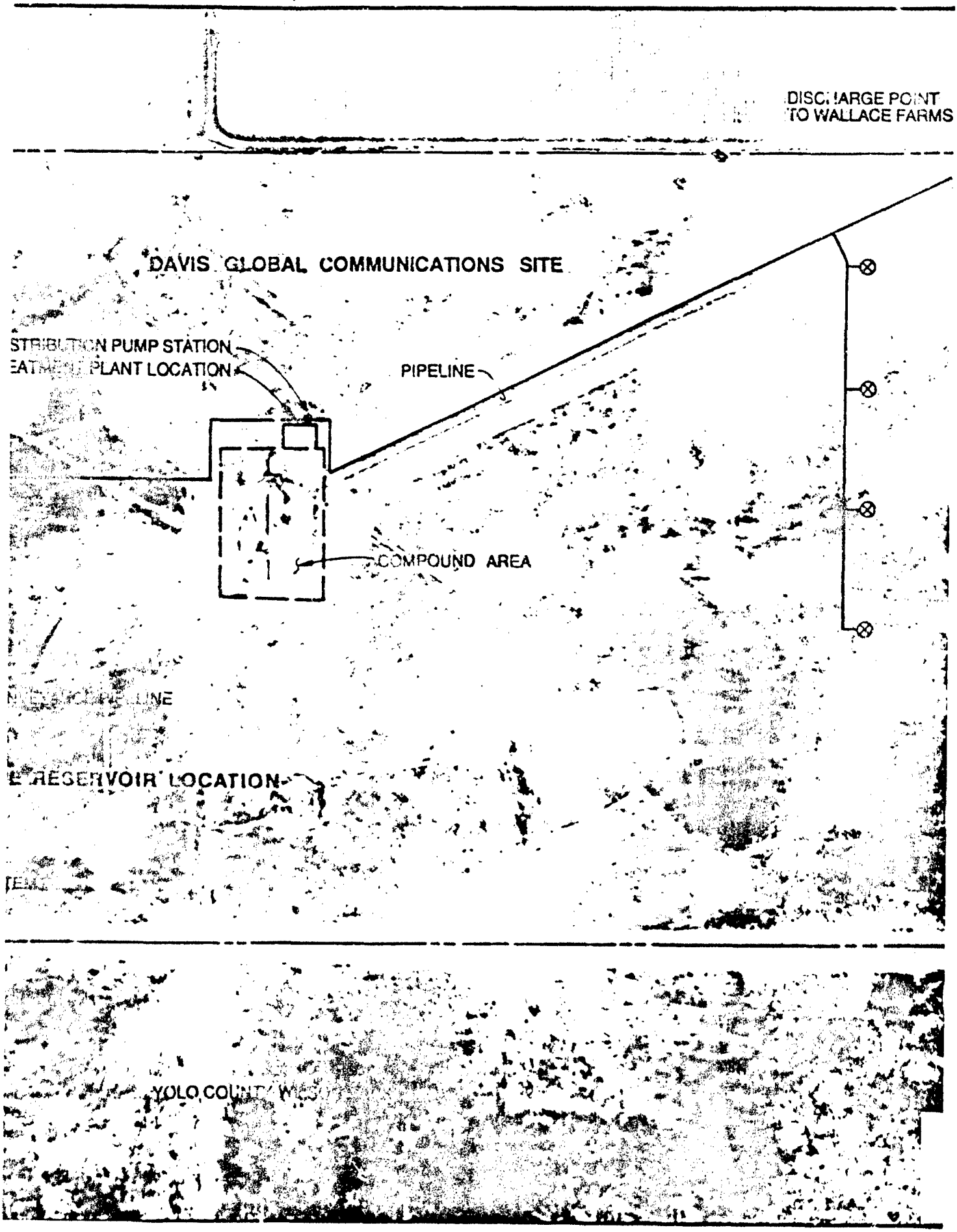
Field Exploration

The onsite soils investigation was conducted during the week of April 26, 1993, by a CH2M HILL soil scientist. This field evaluation consisted of excavation of eight backhoe test pits to expose typical soil profiles for examination, description, sampling, and testing. Duplicate double-ring infiltration tests were conducted at two selected locations on both the surface soils and the restrictive (less permeable) subsoils. In addition, representative soil samples were collected from the two infiltration test profiles for laboratory analysis of chemical properties. The locations of the backhoe test pits are shown in Figure C(a)-1, and the profile logs are shown in Figure C(a)-2.

The evaluation of soil profiles from the test pit excavations and general site observations showed that the site is dominated (Test Pit Nos. 1, 2, 3, 5, and 6) by the Marvin silty clay loam soils found on the basin rim, consisting of moderately slowly permeable silty clay loam surface soils over slowly permeable, dense, silty clay subsoils. The remainder of the site (Test Pit Nos. 4, 7, and 8) is represented by the Brentwood silty clay loam soils found on the alluvial fan physiographic position, consisting of moderately slowly permeable silty clay loam soils. The Brentwood soils have a less developed (less of an increase in clay content) subsoil than the Marvin soils. Both soils are used for irrigated agriculture in the area, but other fields have been graded for surface irrigation, likely because of the slow infiltration rate of the silty clay loam surface textures.

The USDA method duplicate double-ring infiltrometer tests were conducted on two representative soil profiles (Test Pit Nos. A-2 and 7) to determine long-term soil infiltration rates. Tests were conducted both on the undisturbed surface soils and on the restrictive (less permeable) silty clay subsoils. The test results are shown in Table C(a)-2.


POTENTIAL 5-ACRE NATIONAL WEATHER SERVICE RADAR SITE
PROPOSED 55-ACRE IRRIGATED PARCEL
TP A-8
TP A-7
TP A-6
TP A-1
TP A-5
TP A-2
TP A-4
TP A-3
DAVIS
DISTRIBUTION PUMP STATION
PROPOSED TREATMENT PLANT LOCATION
PIPE
IRRIGA
PUMP
STATION
CONVEYANCE PIPELINE
PROPOSED ON-SITE RESERVOIR LOCA
SIDE-ROLL IRRIGATION SYSTEM
LEGEND
TEST PIT LOCATION AND DESIGNATION
TP A-1
YOLO CO


DISCHARGE POINT
TO WALLACE FARMS
DAVIS GLOBAL COMMUNICATIONS SITE
PIPELINE
COMPOUND AREA
YOLO COUNTY

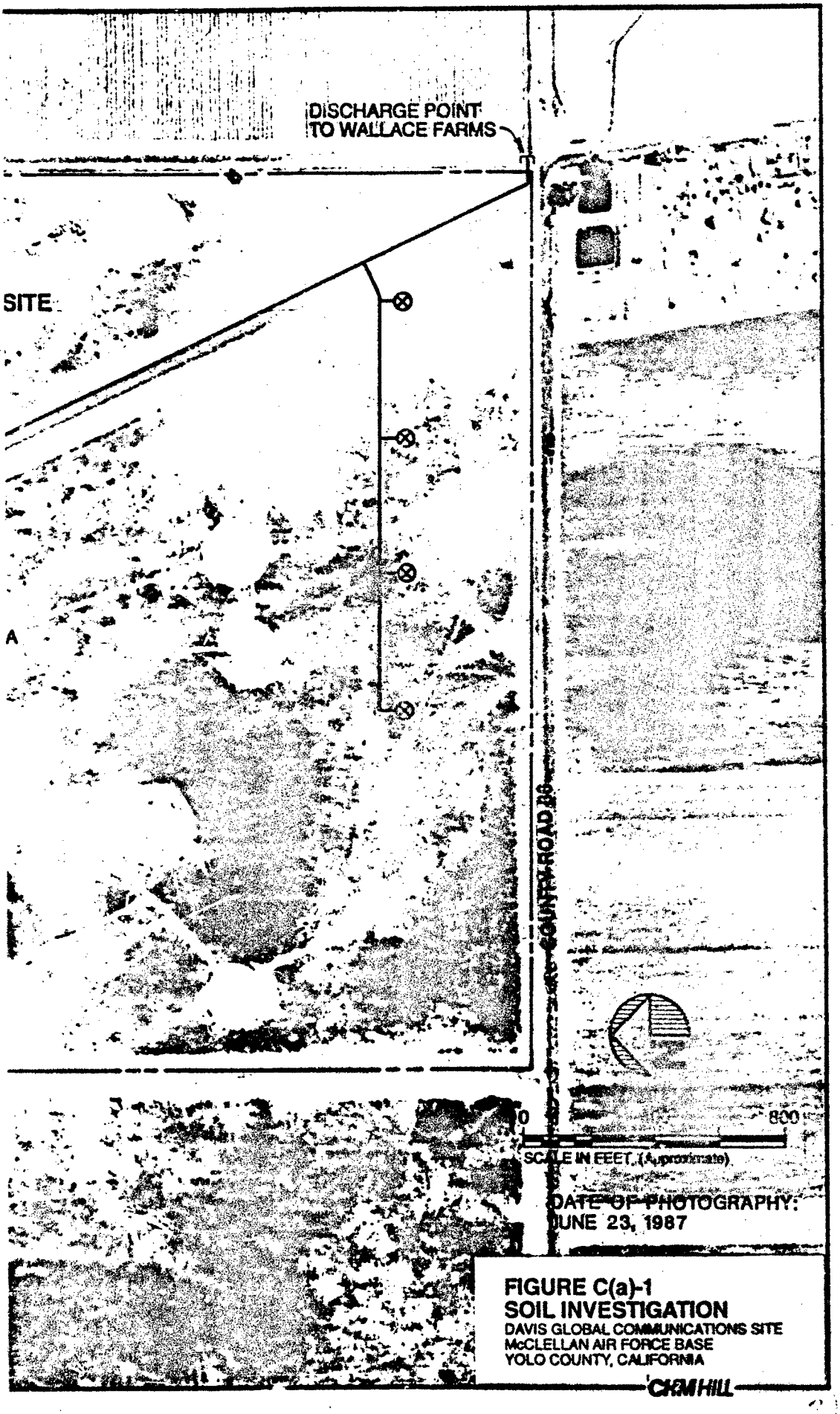
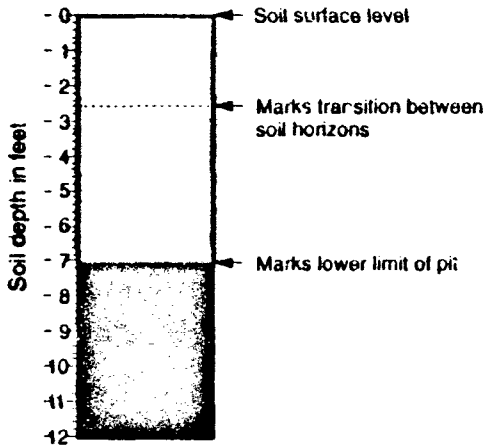


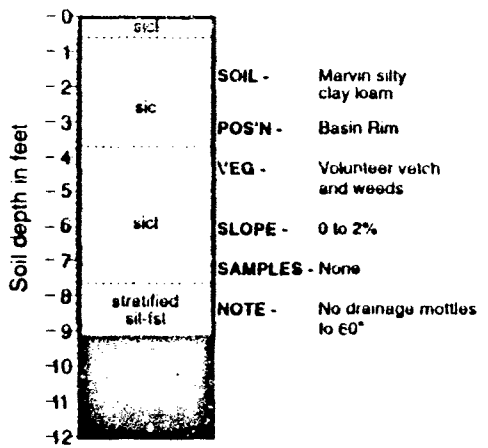
FIGURE C(a)-1
SOIL INVESTIGATION
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2M HILL

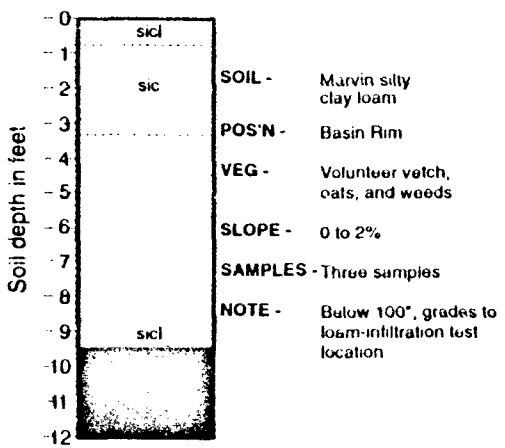
SAMPLE TEST PIT DIAGRAM



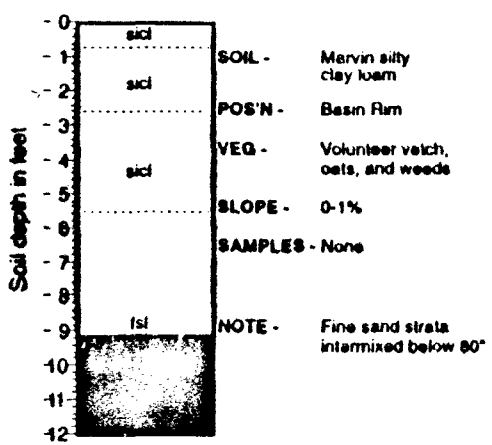
TP A-1



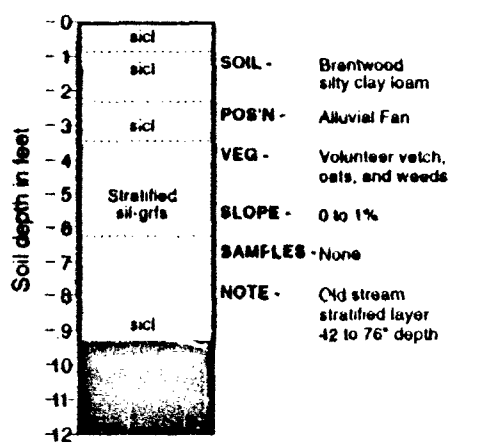
TP A-2



TP A-3



TP A-4



TP A-5

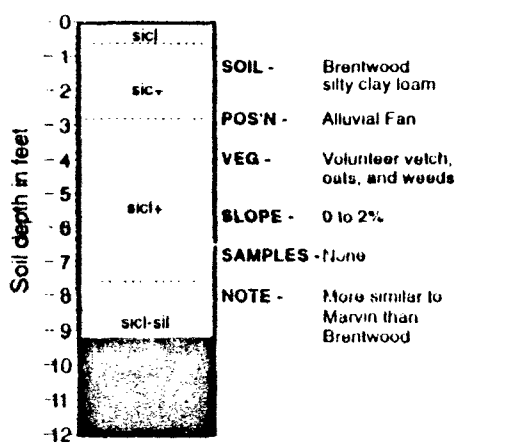
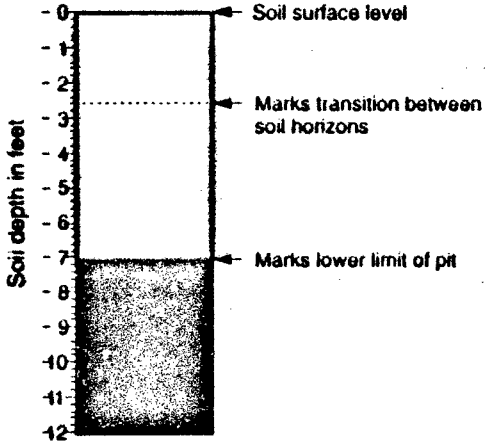


FIGURE C(a)-2
TEST PIT PROFILES,
SOIL INVESTIGATION MAY 1993
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

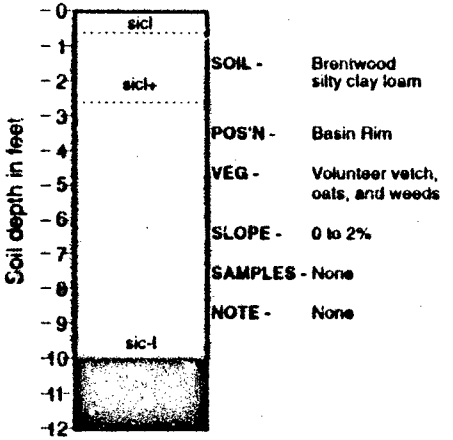
CH2MHILL

RDD1412_203
5055 19

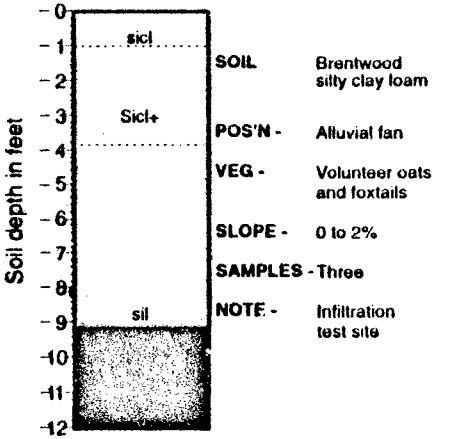
SAMPLE TEST PIT DIAGRAM



TP A-6



TP A-7



TP A-8

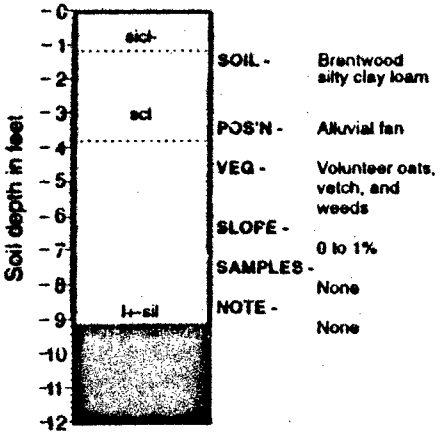


FIGURE C(a)-2 page 2
TEST PIT PROFILES,
SOIL INVESTIGATION MAY 1993
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_204
5055.19

CH2M HILL

Table C(a)-2 Infiltration Rates				
Test Location	Soil Type	Soil Texture/Depth	Infiltration Rate[a] (in/hr)	
			Test 1	Test 2
TP A-2	Marvin silty clay loam	0 to 6 inches silty clay loam surface	0.09	0.16
		18 to 22 inches silty clay subsoil	0.03	0.04
TP A-7	Brentwood silty clay loam	0 to 6 inches silty clay loam surface	0.9	1.2
		20 to 24 inches silty clay loam subsoil	0.06	0.02
[a]USDA duplicate double-ring infiltrometer test method with long-term rates calculated at end of minimum 6-hour test period.				

Representative soil samples were collected from the two typical soil profiles (Test Pit Nos. A-2 and 7) and were sent to the CH2M HILL environmental laboratory for chemical analysis. The results of the laboratory analysis are shown in Table C(a)-3. From a review of the laboratory analyses, the following observations can be made:

- The soil pH values range from 5.9 to 8.0, with surface soils being slightly to moderately acid and the subsoils and substratum nearly neutral to slightly alkaline. These pH values are typical for agricultural soils in the area.

- The electrical conductivity (EC) values ranged from 0.17 to 0.32 mmhos/cm indicating there is very little salt accumulation in the soil profile (nonsaline soils).

- The phosphorus (P) levels ranged from 1.6 to 13 mg/kg and, together with the range of soil pH values, these phosphorus levels are relatively low for agricultural soils in the area. Under nonfarmed volunteer vegetation without fertilization, extractable soil phosphorus levels have been depleted.

- The extractable and water soluble cations (calcium, mercury, sodium, and potassium shown in Table C(a)-3 as Ca, Mg, Na, and K) are within the normal range for agricultural soils in the area except for the relatively high extractable magnesium levels ranging from 10 to 22 milli-equivallents per 100 grams (meq/100 g). Typically, in the arid region soils, calcium is the dominant cation, but because of specific parent materials in the Putah Creek watershed (Serpentine in areas), an

Economists
Scientists

Table C(a)-3

ATTN: Mr. Jim Thayer
Sampled: 04/29/93
Received: 05/03/93

McClellan AFB – Davis Global

CH2M HILL/RDD

SAC28722.55.12

UNITS:		UNIT	%	mmhos/cm	mg/kg	meq/100g Air Dry Soil				meq/100g	meq/100g Air Dry Soil				%
TEST METHOD:		Sat. Paste	Sat. Paste	Sat. Paste Extr.	NaHCO3 Extr.	NH4 AC Extractable				NH4 AC	Water Soluble				K2Cr2O7
SAMPLE DESCRIPTION Ref. No.	Client ID	pH	SAT	EC	P	Ca	Mg	K	Na	CEC	Ca	Mg	K	Na	Organic Matter
35744 – 1	TPA-2 0-9	5.9	36.1	0.23	13	4.9	10.8	0.94	0.19	5.2	0.02	0.05	0.01	0.02	2.70
35744 – 2	TPA-2 9-39	6.5	50.0	0.17	1.6	5.2	20.1	0.40	0.24	8.5	0.02	0.06	<0.01	0.02	1.23
35744 – 3	TPA-2 39-113	7.4	49.9	0.31	6.0	3.1	19.3	0.30	0.26	7.1	0.02	0.15	<0.01	0.03	0.45
35744 – 4	TPA-7 0-12	6.3	38.4	0.23	2.6	5.5	13.2	0.58	0.19	6.3	0.02	0.07	<0.01	0.02	0.47
35744 – 5	TPA-7 12-46	6.8	33.4	0.19	1.6	4.8	22.3	0.40	0.25	9.0	0.01	0.05	<0.01	0.02	1.21
35744 – 6	TPA-7 46-110	8.0	40.9	0.32	8.8	4.8	18.9	0.24	0.28	4.0	0.02	0.12	<0.01	0.03	0.17

C-8

Approved by: Randall Wright for DCH Date: 5/26/93
5/25/93

imbalance exists where magnesium significantly exceeds calcium. In personal communication with Dr. Randy Southard, University of California, Extension Soil Specialist, he has indicated the same relationship (magnesium imbalance) was documented on the University of California Davis campus on the Marvin and Brentwood soils.

- The cation exchange capacity (CEC) values range from 4.0 to 9.0 meq/100 g and are relatively low for agricultural soils in the area. CEC is generally a function of soil clay content and organic matter, but may be effected by the dominance of magnesium. Similar soils in the area have documented CEC values of 15 to 20 meq/100 g.

- The soil organic matter levels range from 0.4 to 2.7 percent, with the normal highest level in the surface soils and a sharp decline in organic matter levels with depth, typical of agricultural soils. The evaluated 1.2 percent in Test Pit A-7, 12 to 46 inches, may be caused by an old buried surface soil in that area.

Conclusions and Recommendations

From the soil investigation, discussions with local soil scientists, and the overall evaluation of soil suitability for treated groundwater reuse, the following conclusions and recommendations can be made:

- In the site soils, both the Marvin and Brentwood silty clay loam mapping units have a moderately slow surface permeability, and the subsoils are slowly permeable as defined by the USDA/SCS soil mapping. In CH2M HILL's field testing, the surface infiltration rates ranged from 0.09 to 1.2 inch/hour, and the subsoils are greatly restrictive to water movement ranging from 0.02 to 0.06 inch/hour. Therefore, under irrigation, long-term application rates and duration of irrigation will be restricted, with application rates of 0.1 to 0.15 inch/hour.

- The irrigation site is gently undulating with a minor drainageway to the southeast on the southern border. All of the adjacent irrigated farmland has been surface-graded for flood irrigation (likely because of slow infiltration rates), but that practice is not feasible on this site because of significant cuts and fills and exposure of less permeable subsoils. Irrigation should be restricted to sprinkler irrigation with onsite runoff control and recycling to the irrigation storage reservoir.

- From a soils standpoint, the soils are manageable for irrigation under a permanent forage cropping operation as long as a high level of irrigation scheduling and management is implemented. The soils are not restricted by fertility, and under normal fertilization practice, crop production should be high.

Works Cited

CH2M HILL. 1993. *Final Davis Global Communications Site Intermediate Remedial Design Report.* June 3.

Southard, Dr. Randy. 1993. Phone conversation. University of California. April.

U.S. Department of Agriculture/Soil Conservation Service. 1972. *Yolo County Soil Survey.* June.

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Sara Monteith/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Geotechnical Exploration for the Onsite Reservoir
Davis Global Communications Site
Delivery Order 5055

PROJECT: SAC28722.55.12

Purpose and Scope

This technical memorandum provides a summary of field observations, laboratory testing, discussion, and preliminary recommendations for the proposed onsite reservoir at the Davis Global Communication Site (the Davis Site), located approximately 20 miles southwest of McClellan Air Force Base (McClellan AFB) in a predominantly agricultural area near the Yolo-Solano County border. Various volatile organic compounds have been detected at the facility to depths up to 65 feet below ground surface (bgs). The proposed onsite reservoir will provide aboveground storage for treated groundwater that will be used for irrigation for agricultural purposes. Further details including groundwater conditions, constituents of contamination, extent of contamination, and preliminary costs for this onsite reservoir and irrigation system are provided in the *Final Davis Global Communications Site Intermediate Remedial Design Report* (CH2M HILL, 1993).

Background

The location of the proposed onsite reservoir is shown in Figure C(b)-1. Elevations at the reservoir site were not measured; however, the ground surface elevation of nearby wells is approximately 30 feet mean sea level. The topography over the reservoir site is relatively level, with a small depression in the southwest corner. This depression appears to be part of a vestigial overflow channel. The site is subject to periodic flooding during periods of sustained rainfall because of the lack of relief.

Vegetation at the reservoir site consists of grasses, thistles, and wildflowers. At the time of the field exploration (April 29, 1993), the reservoir area was covered with dense, green grasses and wildflowers approximately 4 feet tall. By late spring or early summer, these grasses will be dry. The reservoir area is bounded by two antennas on

the south, by one on the east side, and by one on the west. No other signs of development were apparent at the time of the field exploration.

Local frost penetration does not typically exceed 6 inches.

The proposed onsite reservoir will be overexcavated below the existing ground surface to provide a basin for water storage and to provide fill for the reservoir embankment. The crest will be 12 feet above the interior of the reservoir and 4 feet above the existing ground surface on the exterior of the reservoir. Approximately 2 feet of overexcavation will be required at the exterior toe. The embankment will have 3:1 slopes on both interior and exterior faces and a crest width of 15 feet, resulting in a total cross-sectional width of approximately 80 feet. A schematic profile of the embankment is shown in Figure C(b)-2.

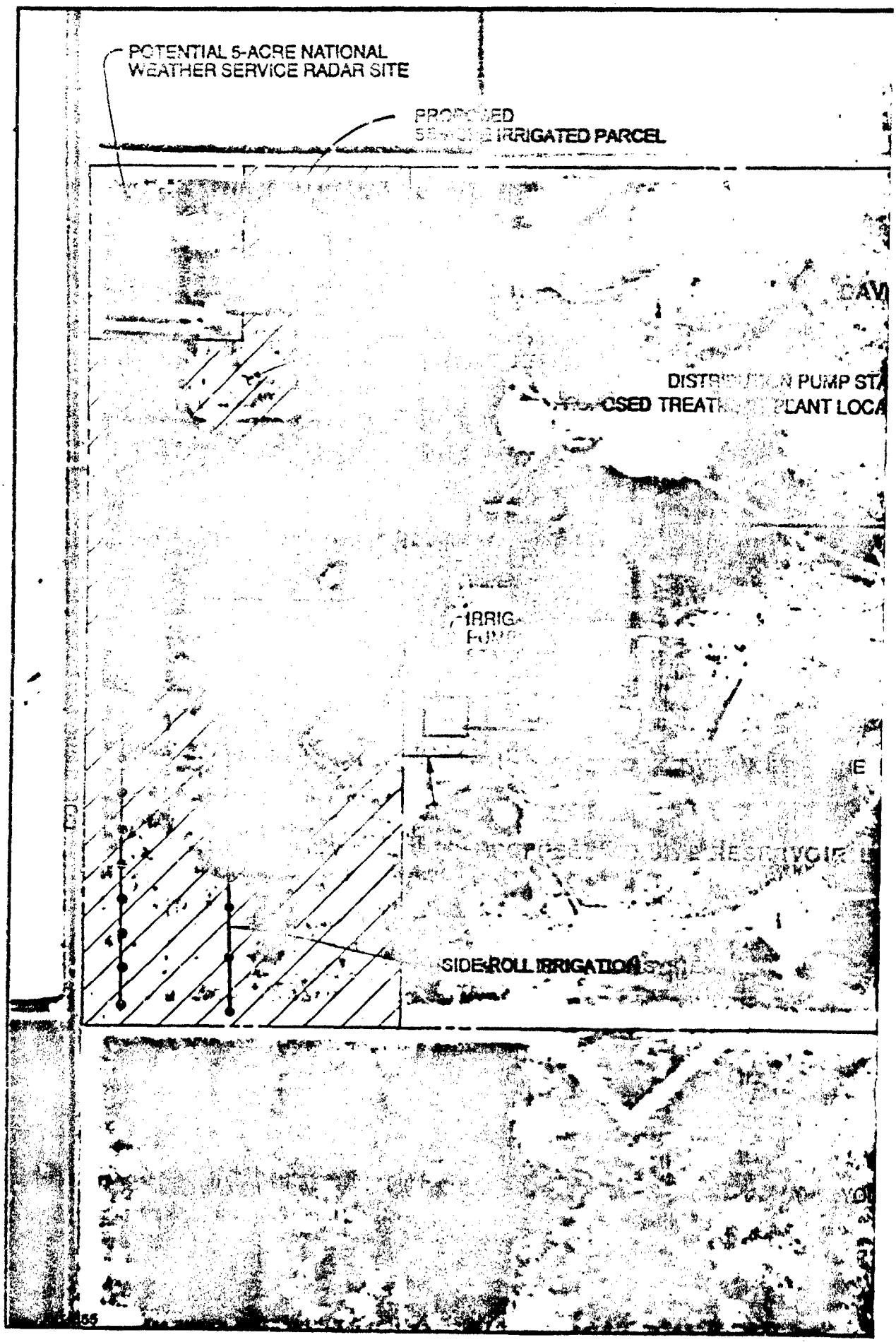
The maximum depth of water to be stored in the reservoir is 10 feet, with a minimum freeboard of 2 feet. The volume of water stored in the reservoir under full conditions is approximately 5 acre-feet. A reservoir design of this type is not under the jurisdiction of the State of California Division of Safety of Dams (State of California, Statutes and Regulations Pertaining to Supervision of Dams and Reservoirs, 1992.)

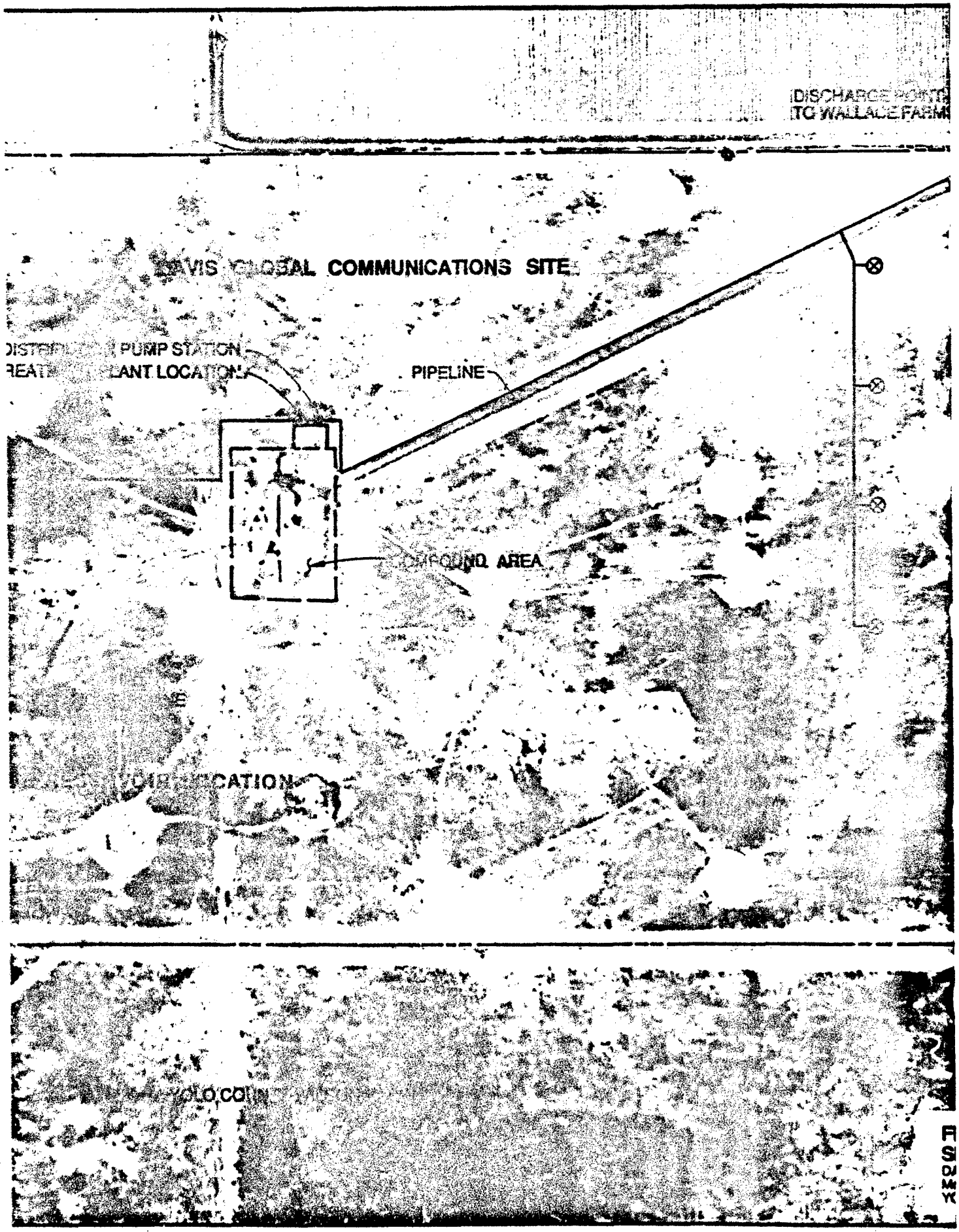
Limitations

This memorandum has been prepared for the exclusive use of McClellan AFB for specific application to the onsite reservoir at the Davis Site in accordance with generally accepted geotechnical engineering practice. No other warranty, expressed or implied, is made.

The recommendations contained in this memorandum are based on the data obtained from test pit excavations and field observations. Test pit excavations indicate subsurface conditions only at specific locations and times and only to the depths excavated. They do not necessarily reflect strata variations that may exist between such locations. If variations from those subsurface conditions described are noted during construction, recommendations in this memorandum must be reevaluated.

In the event that any changes in the nature, design, or location of the facilities are planned, the recommendations contained in this memorandum should not be considered valid unless the changes are reviewed and this memorandum modified or verified in writing by CH2M HILL. CH2M HILL is not responsible for any claims, damages, or liability associated with interpretation of subsurface data or reuse of the subsurface data without the express written authorization of CH2M HILL.


POTENTIAL 5-ACRE NATIONAL
WEATHER SERVICE RADAR SITE
IRRIGATED PARCEL
SIDE-ROLL IRRIGATION


DISCHARGE POINT
TO WALLACE FARM
DAVIS GLOBAL COMMUNICATIONS SITE
PUMP STATION
PLANT LOCATION
PIPELINE
COMPOUND AREA
LOCATION
YOLO COUNTY

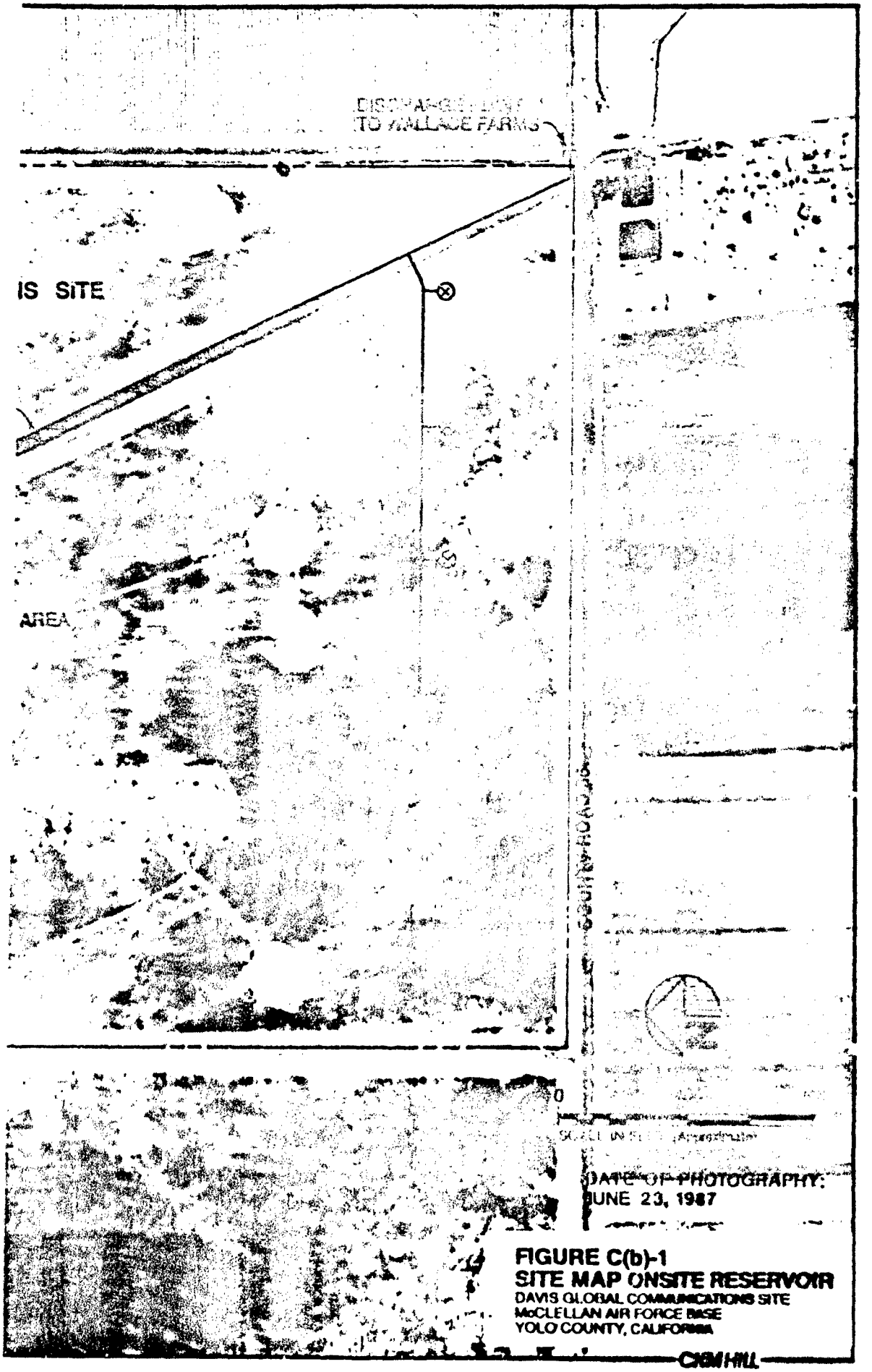
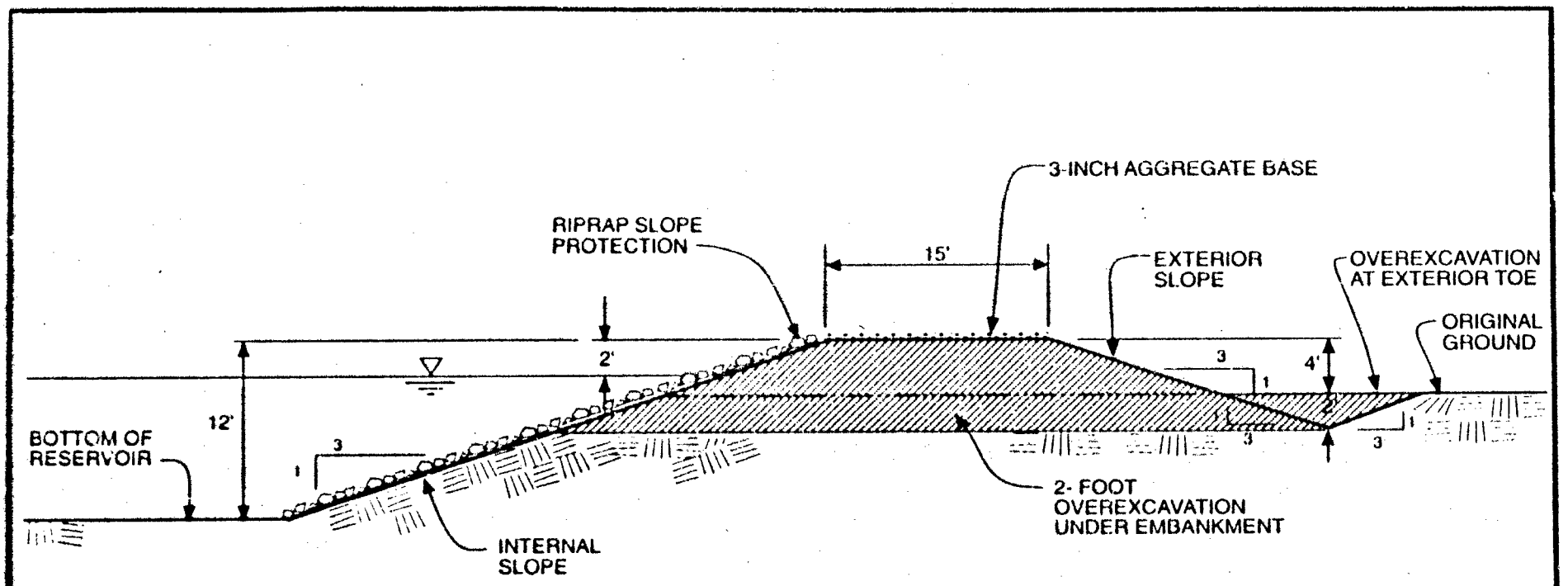


FIGURE C(b)-1
SITE MAP ONSITE RESERVOIR
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2M HILL



LEGEND

- ENGINEERED FILL
- UNDISTURBED ORIGINAL GROUND
- AGGREGATE BASE
- RIPRAP

SCALE: 1" = 10'
(Approximate)

FIGURE C(b)-2
SCHEMATIC OF EMBANKMENT PROFILE
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2M HILL

RDD1412.205

Field Exploration

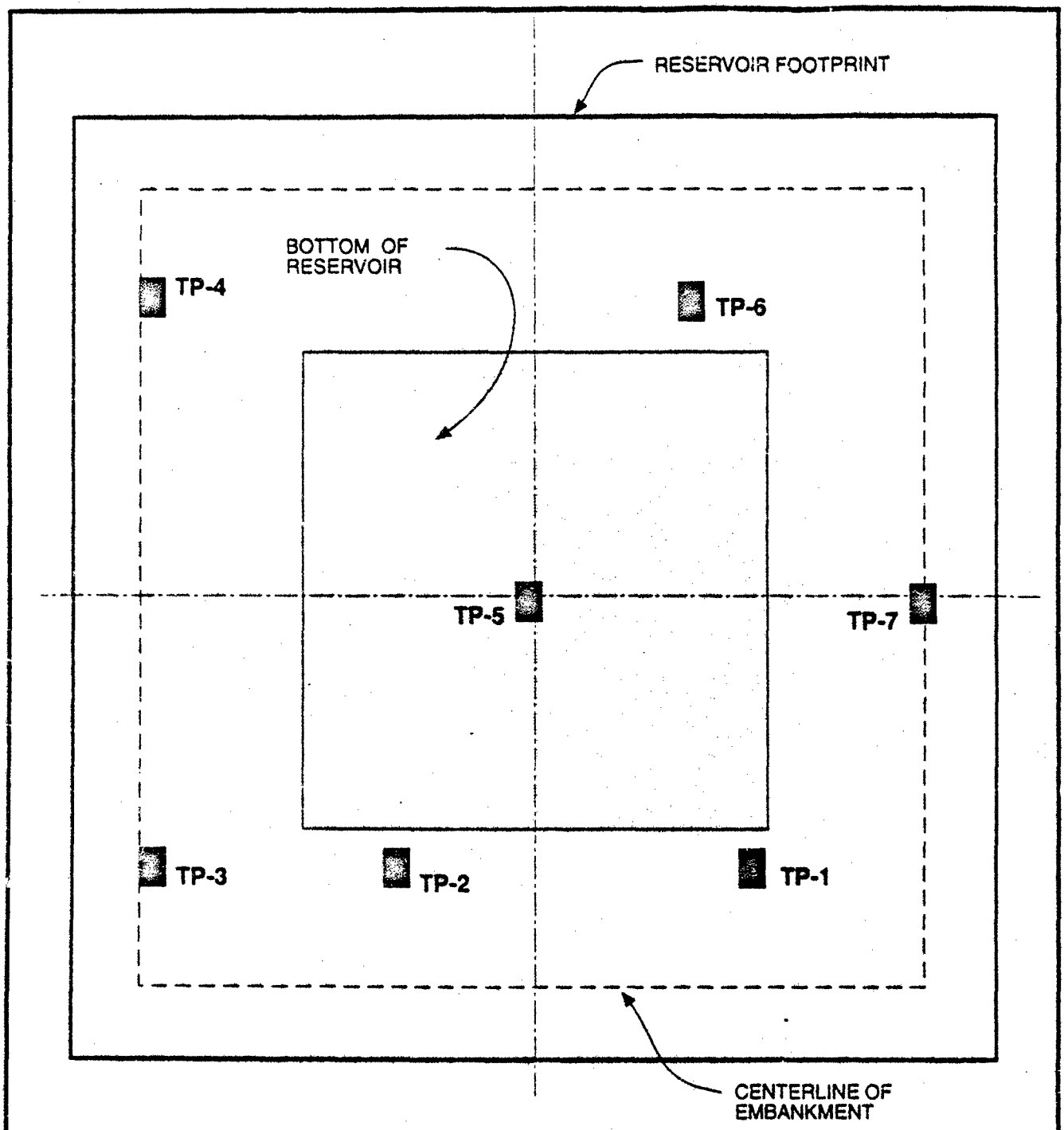
The field exploration, conducted on April 29, 1993, included excavating seven test pits in the footprint of the reservoir and collecting soil samples from each test pit. Test pit locations are shown in Figure C(b)-3. The test pits were excavated by Ramcon of West Sacramento, using a John Deere C410 backhoe. Depths explored ranged from 8 to 10 feet bgs. Soil collected from each test pit was logged in accordance with the Unified Classification System (ASTM D 2488); this classification was later verified with results of laboratory testing (using ASTM D 2487). Following logging of each test pit, the pits were backfilled with the material excavated. Test pit logs are included as Appendix A, Soil Gas Investigation. The backhoe compacted the soil after replacing it to reduce settlement. Approximate test pit locations were measured with a rag tape and a compass.

Subsurface Conditions

Subsurface conditions were generally quite uniform in the test pit excavations. Soil observed in the test pits includes two clay layers. The "upper" layer, typically 2 to 4 feet thick, is a moist, dark moderate brown clay, with moderate to high plasticity, and a hard consistency. Root penetration is typically to 1.5 feet bgs. Pocket penetrometer measurements performed on the sidewalls in this layer yield unconfined compression strengths ranging from 3 to 5 tons per square foot (tsf). The "lower" layer is a moist, moderate brown clay, with moderate plasticity and a stiff to very stiff consistency. Moisture content appears to increase with depth. Pocket penetrometer measurements performed on the lower clay yield generally lower unconfined compression strengths, ranging from less than 1 to 3.5 tsf. This apparent reduction in strength may be related to increased moisture content.

In Test Pit TP-3, excavated in the depression of the vestigial overflow, a silty sand with gravel was observed between 6 and 9.5 feet bgs. The gravel was typically 2-inch minus, well-graded and well-rounded. Below this gravel layer, a clay similar to the lower clay layer described above was observed. Test Pit TP-3 was the only test pit in which gravel was observed. However, review of logs for wells drilled at the Davis Site indicate this area exhibits some lateral variability, that is, occasional interfingering of gravel and sand lenses within the clay layers. Therefore, although additional gravel or sand lenses are not anticipated, they may be encountered during reservoir construction.

Sidewalls for the test pits remained vertical and did not exhibit any tendency to immediately cave, except in the gravel layer in TP-3. Excavation of the soil was accomplished easily. No groundwater was encountered in the test pits.



LEGEND

TP-1 TEST PIT LOCATION

NOTE: Reservoir footprint does not include overexcavation at upstream and downstream toes of embankment.

N

1" = 40'

FIGURE C(b)-3
TEST PIT LOCATIONS
DAVES GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_206
5055 19

CH2MHILL

Laboratory Testing

Soil samples obtained during the field exploration were submitted for laboratory testing at MTI Testing Laboratory in Redding, California. Because of uniformity of subsurface conditions, laboratory testing was limited to the following tests:

- Atterberg Limits (ASTM D 4318)
- Material Passing No. 200 Sieve (ASTM D 1140)
- Grain Size Distribution (ASTM D 422) (1.5 inches to No. 200 Sieve)
- Moisture Density Relationship (ASTM D 698)

Representative samples were selected from Test Pits TP-2, TP-4, and TP-6, and a sample of gravelly material was selected from TP-3. A summary is provided in Table C(b)-1. Results are provided in Appendix B, Air Permeability Testing.

Table C(b)-1
Laboratory Testing Summary

Test Pit No.	Sample Depth (ft bgs)	Atterberg Limits (LL/PI)	Percent Passing No. 200	Grain Size[a]	Maximum Dry Density (pcf)	Optimum Moisture Content (%)
TP-2	Composite				103.6	17.1
TP-3	6			X		
TP-4	0 to 2		76.3			
TP-4	4 to 6		82.9			
TP-6	0 to 3	47/23				
TP-6	3 to 8	31/10				

[a]Grain size distribution presented in Appendix B.

Conclusions and Recommendations

Field observations and laboratory testing indicate that subsurface conditions at the Davis Site are generally favorable for the proposed onsite reservoir. The following design considerations and recommendations for additional work should be performed prior to developing plans and specifications:

- The depression located in the southwest corner of the reservoir site will require additional earthwork during construction of the embankment. In addition, the presence of gravel in the embankment foundation may result in piping or seepage problems. The reservoir location should be adjusted 50 to 100 feet south or west to mitigate these potential problems.

Additional test pits may be excavated at the new reservoir site; however, subsurface conditions were quite consistent in the other six test pits excavated within the reservoir footprint. In addition, test pits excavated over the extent of the adjacent irrigation parcel (excavated for soil survey) indicated similar subsurface conditions throughout.

- Sieve analyses performed on an upper clay sample and a lower clay sample resulted in 76 and 83 percent of the soil passing the No. 200 sieve, respectively, indicating a low permeability soil suitable for embankment construction. According to field observations, laboratory testing, and pocket penetrometer measurements, it appears that 3:1 slopes will be acceptable for the interior and exterior slopes of the reservoir. Slope stability analyses will be required to verify these assumptions.

  From a root penetration of 1.5 feet bgs observed in test pits, 2 feet of overexcavation should be performed under the embankment (as shown in Figure C(b)-2).

- If the water supply in the reservoir is rapidly depleted, the interior slopes will be subject to rapid drawdown conditions. Additional stability analysis will be required to analyze embankment performance under these conditions.

- The reservoir is located in Uniform Building Code (UBC) Seismic Zone 3. It may be necessary to perform a review of site seismicity and pseudostatic slope stability analysis to evaluate the performance of the embankment under seismic loading.

- Field observations and logs for nearby wells do not indicate that the reservoir excavation will be under the influence of groundwater.

- Riprap or an equivalent slope protection should be placed on the interior slopes of the reservoir to protect the embankment from wave action caused by wind.

- Additional laboratory testing should be performed for design of the onsite reservoir. This testing may include, but should not be limited to, additional strength testing and testing of corrosion potential. Permeability testing may be performed for seepage analysis or determination of uplift pressures.

Works Cited

CH2M HILL. 1993. *Final Davis Global Communications Site Intermediate Remedial Design Report.* Delivery Order No. 5055. June.

State of California. 1992. Statutes and Regulations Pertaining to Supervision of Dams and Reservoirs.

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Rob Pexton/CH2M HILL, Sacramento

DATE: September 9, 1993

SUBJECT: Summary of Field Activities
Davis Global Communications Site
Delivery Order 5055

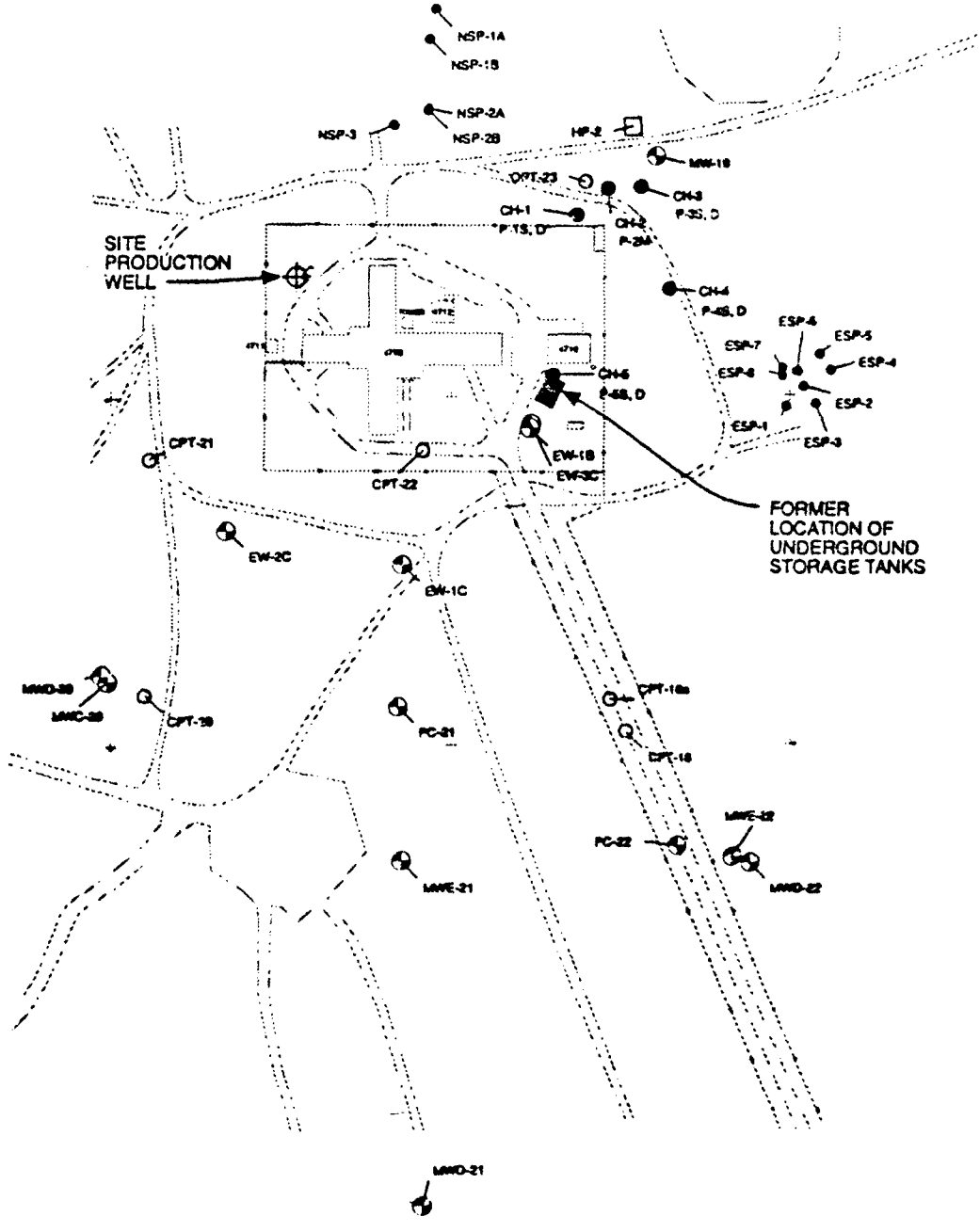
PROJECT: SAC28722.55.18

Purpose and Scope

CH2M HILL conducted a series of remedial investigation field activities at the Davis Global Communications Site (Davis Site) in 1992 and 1993 in accordance with the Work Plan for the Site (CH2M HILL, 1993). These activities were performed to increase understanding of the subsurface chemical and hydrogeologic conditions and to facilitate implementation of remedial measures. The surveyed locations of all activities conducted both in the compound and at the north edge of the site are shown in Figure D-1. A summary of previous remedial field activities is included in Chapter 2 of the RI/FS Report.

CH2M HILL activities performed in and near the compound include:

- Dry or partially submerged groundwater Monitoring Wells MW-1, MW-3, MW-5, and MW-7 were sampled for soil gas in August 1992. Details and results are given in Appendix A, Soil Gas Investigation.
- Aquifer testing was performed on Monitoring Wells MWC-3, MWC-12, and MWC-14 in August 1992, and Monitoring Wells MWD-12 and MW-3 in January 1993. Results are given in two separate reports (CH2M HILL, 1992 and 1993).
- Collecting shallow soil gas samples and samples from August through October 1992. Details are provided in Appendix A, Soil Gas Investigation.
- Collecting and analyzing soil samples from the north and east soil piles in November 1992. Discussion is included in this appendix.



LEGEND

- ○ CONE PENETROMETER SOUNDING
- ◐ GROUNDWATER MONITORING WELL
- □ HYDROPUNCH
- ● SOIL VAPOR MONITORING WELL
- ⊕ SOIL PILE

N

SCALE (Approximate)

0 250 FEET

FIGURE D-1
CH2M HILL FIELD ACTIVITY LOCATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY CALIFORNIA

CH2M HILL

RDD1412_207
5055.19

- Six Cone Penetrometer (CPT) soundings (CPT-18, CPT-18A, CPT-20, CPT-21, CPT-22, and CPT-23) performed in November 1992 to investigate site stratigraphy. Discussion is included in this appendix.

- Five Soil Vapor Monitoring Wells (SVMWs) (CH-1 through CH-5) and adjacent piezometers (P-1S, P-1D, P-2M, P-3S, P-3D, P-4S, P-4D, P-5S, and P-5D) were drilled and installed in November 1992 to investigate the vadose zone chemical and hydrogeologic properties. Discussion is provided in this appendix. A summary of results of sampling of SVMW and adjacent piezometers is in Appendix A. Discussion of air permeability testing, performed in December 1992, is presented in Appendix B, Air Permeability Testing.

- Four Groundwater Extraction Wells (EW-1B, EW-1C, EW-2C, and EW-3C) were drilled and installed in April and May 1993 to capture contaminated groundwater from the B and C aquifers.

- Eight test pits were excavated and double-ring infiltration tests were conducted in April 1993, as part of an investigation for land application of treated groundwater. Details and discussion are provided in Appendix C(a), Treated Groundwater Reuse Soils Investigation.

- Seven test pits were excavated and soil samples were collected and tested as part of a preliminary investigation to assess the feasibility of constructing an onsite reservoir to store treated groundwater. Discussion and results are presented in Appendix C(b), Geotechnical Exploration for the Onsite Reservoir.

- Groundwater levels were measured biweekly from July to December 1992, and monthly during 1993. Results are summarized in Appendix E, Groundwater Contour Maps.

- Groundwater levels were collected hourly using a data logger from Well Cluster MW1 from July 1992 to June 1993. A graph of those levels is presented in the RI/FS Report as Figure 3-6.

- Seven new Groundwater Monitoring Wells (MW-19, MWC-20, MWD-20, MWD-21, MWE-21, MWD-22, and MWE-22) and two groundwater piezometers (PC-21 and PC-22) were installed in May and June 1993 to improve definition of the horizontal and vertical extent of groundwater contamination. A Hydropunch sample, HP-2, was taken and analyzed near the location of MW-19 prior to well installation to determine the most effective well location. Groundwater samples were collected during drilling of MWD-20, MWE-21, and MWE-22 to improve the placement of subsequent monitoring wells. A discussion is provided in this appendix. Well completion data are provided in Appendix S, Well Construction Data. Analytical results are presented in Appendix U, Historic Contaminant Data.

CH2M HILL activities performed at the north edge of the Davis Site include:

- Two CPT soundings (CPT-24 and CPT-25) were performed about 300 feet south of County Road 35 in April 1993 to locate a favorable site for an injection well to dispose of treated groundwater. A test hole (TH-1) drilled at this location was sampled and geophysically logged in June 1993. The borehole was then abandoned by tremie grouting following geologic and geophysical logging. Logs are provided in Appendix Q.

Radian Corporation sampled all new and existing wells at the site in early July 1993, as part of the McClellan AFB groundwater sampling and analysis program. Water quality results are pending.

Subsurface Conditions

In general, the stratigraphy underlying the Davis Site consists of clay with moderately continuous lenses of sand and silty sand, and less common lenses of gravel. The soil profile has been divided roughly into five zones, "A" through "E", which apply to the area around the buildings at the Davis Site. The upper zone, designated the A "aquifer," contains one or two layers of coarse-grained material. The first layer is located between 13 and 18 feet below ground surface (bgs); the second layer is between 25 and 35 feet bgs. The B aquifer is located between about 65 and 95 feet; the C aquifer between about 95 and 145 feet bgs; the D aquifer between about 145 and 195 feet bgs; and the E aquifer between about 195 and 245 feet bgs. These zones are variable in thickness and are somewhat laterally discontinuous across the site.

Field Exploration

Ex Situ Soil Sample Collection

Two areas of existing soil piles have been identified outside the Main Compound Area southeast of Building 4710. The soil piles have been identified as the northern pile and the eastern pile. The northern pile is from the initial excavation of the diesel storage tanks (when the soil was removed to expose the tanks). The eastern pile is from the excavation and removal of the three diesel tanks (Personal Communication, Dave Phillips). These piles do not appear to have been disturbed since their placement; however, rodent burrows have been observed in the piles. The eastern and northern piles comprise approximately 560 and 320 cubic yards, respectively.

A total of 14 soil samples were collected in November 1992 from the soil piles, five from the northern pile (NSP-1A, -1B, -2A, -2B, and -3), and nine from the eastern pile (ESP-1 through ESP-9). Samples were obtained using a hand auger to drill to 1 to 2 feet bgs. The samples were analyzed for total fuel hydrocarbons as diesel using EPA Method 8015 Modified and for total petroleum hydrocarbons as diesel using

EPA 418.1. Levels of diesel contamination ranged nondetect from 640 mg/kg. Results are presented in Appendix U.

Cone Penetrometer Soundings

Six CPT soundings, CPT-18 through CPT-23, were advanced at the Davis Site by Tonto Drilling of Sacramento, California, in November 1993. The intention of these soundings was to advance the probe to a depth of approximately 150 feet to evaluate the C and D aquifers. However, probe refusal on hard material or excessive inclination of the probe prevented penetration greater than 113 feet bgs. Table D-1 provides a summary of maximum depth for each sounding and the cause of probe refusal. CPT logs are provided in Appendix R, Cone Penetrometer Data.

Table D-1
CPT Borings at Davis Global Communications Site

Sounding	Depth	Reason for Stopping
CPT-18[a]	58.23	Unable to push farther
CPT-18A[b]	113.2	12 degree inclination
CPT-19[c]	5.7	Electrical Interference
CPT-19A	4.1	Electrical Interference
CPT-20	98.43	12 degree inclination
CPT-21	86.94	12 degree inclination
CPT-22	52.49	Unable to push farther
CPT-23	95.96	12 degree inclination

[a]CPT-18 could only be advanced to a 58.2-foot depth.
[b]CPT-18A was advanced about 50 feet northeast of CPT-18.
[c]CPT-19 was attempted southeast of CPT-20, but equipment problems and electrical interference from a transmitter tower prevented completion of the boring.

Soil Vapor Monitoring Wells and Vapor Piezometers

SVMWs and piezometers were installed at the Davis Site in November 1992 at the locations shown in Figure D-1. Well locations were selected using the results of shallow soil gas sampling described in Appendix A, Soil Gas Investigation. The SVMWs installed include the following:

- Five vapor extraction wells, CH-1 through CH-5
- Four "shallow" piezometers, P-1S, and P-3S through P-5S (adjacent to CH-1, and CH-3 through CH-5, respectively)
- One intermediate depth piezometer, P-2M (adjacent to CH-2)

- Four "deep" piezometers, P-1D, and P-3D through P-5D (adjacent to CH-1, and CH-3 through CH-5, respectively)

The wells were constructed in boreholes advanced with an 8-inch hollow-stem auger by Westex Drilling of West Sacramento, with piezometers placed in an adjacent borehole. Standard Penetration Tests (SPTs) were performed at approximate 5-foot intervals, and soil samples were logged in general accordance with the Unified Soil Classification System (ASTM D 2488). The SVMWs were originally drilled to a total depth ranging from 61.5 to 71.5 feet bgs so that the stratigraphy below the wells could be logged. The borehole was then backfilled with bentonite chips to the desired depth, and the well was constructed. Locations and elevations of the installations were surveyed by CH2M HILL. Boring logs and well construction diagrams are attached as Appendixes Q and S, respectively.

The extraction wells and their associated piezometers are screened within the A aquifer. The vapor extraction wells consist of 2-inch Schedule 40 PVC with a screened interval of 10 feet, except CH-2 which has a screened interval of 2 feet. The piezometers are constructed of a 1-inch-diameter Schedule 40 PVC, with a screened interval of 2 feet for shallow piezometers, 5 feet for the intermediate depth piezometer, and 10 feet for deep piezometers. A summary of installation details is provided in Table D-2.

Table D-2
Summary of Vapor Well and Piezometer Details

Well/ Piezometer No.	Description	TOC Elevation (feet msl)	Screened Interval (feet bgs)	Gravel Pack Interval (feet bgs)	Description of Soil Adjacent to the Screened Interval
CH-1	2-inch well	28.7	25 to 35	21 to 37	Sandy Silt/Silty Sand
P-1S	1-inch piezometer	27.62	14 to 16	13.5 to 17	Clay w/trace Sand
P-1D	1-inch piezometer	27.29	48 to 58	43 to 60	Clay w/Sand
CH-2	2-inch well	28.18	14 to 16	13.5 to 17	Silty Sand/Sandy Silt
P-2M	1-inch piezometer	27.54	30 to 35	28 to 36	Sand and Gravel w/Silt
CH-3	2-inch well	27.83	22 to 32	20 to 33	Sand w/Gravel and Silt
P-3S	1-inch piezometer	27.48	15 to 17	14.5 to 18	Sand and Silt
P-3D	1-inch piezometer	27.21	48 to 58	46 to 60	Clay
CH-4	2-inch well	28.34	27 to 37	26 to 40	Sand w/Clay and Silt
P-4S	1-inch piezometer	27.67	17 to 19	15 to 20	Clay
P-4D	1-inch piezometer	27.73	45 to 55	41 to 56	Clay
CH-5	2-inch well	28.49	28 to 38	26 to 39	Clayey Sand/Clayey Gravel
P-5S	1-inch piezometer	28.37	18 to 20	17 to 22	Sandy Clay
P-5D	1-inch piezometer	28.36	45 to 55	43 to 58	Clay

Soil samples were collected from boreholes for CH-1 through CH-5 at approximate 5-foot intervals. Selected samples were submitted for analytical and physical testing. Results are summarized in Table D-3. A complete listing of the results is provided in Appendix U.

Table D-3
In Situ Soil Analyses
(SVMW Borings)

Boring	Depth (ft/bgs)	Semi-volatile Organic Compounds SW 8270	Total Recoverable Petroleum Hydrocarbons EPA 418.1 (mod.) (mg/kg)	TPH-Diesel[a] SW 8015 (mg/kg)	ICP Metals SW 6010	Mercury SW 7471 (mg/kg)	Arsenic SW 7060 (mg/kg)	Lead SW 7421 (mg/kg)	Bulk Density ASA #9 30.2 (gm/cc)	Total Organic Carbon EPA 415.1 (mg/kg)	Particle Size ASTM D422	Moisture Content ASTM D2216 (percent)	Specific Gravity ASTM D854 (unitless)
CH-1	0 to 1.5	[b]	<1.8 mg/kg	NL/	[b]	0.08 mg/kg	4.8 mg/kg	7.7 mg/kg					
	10 to 11.5	[b]	<2.0 mg/kg	ND	[b]	0.14 mg/kg	4.8 mg/kg	6.4 mg/kg					
	35 to 36.5								1.85g/cc		[a]	11.2	
	50 to 51.5								1.98g/cc		[a]	21.0	
CH-2	0 to 1.5	[b]	34.3 mg/kg	ND	[b]	0.08	6.4 mg/kg	7.1 mg/kg					
	10 to 11.5	[b]	0 mg/kg	ND	[b]	0.13	7 mg/kg	6.7 mg/kg					
	25 to 26.5								1.56		[a]	12.9	2.72
CH-3	0 to 1.5	[b]	<1.9 mg/kg	ND	[b]	0.11 mg/kg	7.4 mg/kg	8.5 mg/kg					
	10 to 11.5	[b]	<2.0 mg/kg	ND	[b]	0.13 mg/kg	4.3 mg/kg	7.9 mg/kg					
	15 to 16.5								1.55		[a]	8.6	2.71
	27.5 to 29								1.13		[a]	16.3	2.72
	50 to 51.5								1.76		[a]	15.8	2.72
	30 to 31.5									2,010			
	33 to 34.5									2,690			
	40 to 41.5									732			
	55 to 56.5									967			
	66 to 67.5									1,470			
CH-4	0 to 1.5	[b]	9.6	ND	[b]	0.11	6.3	7.2					
	10 to 11.5	[b]	8.8	ND	[b]	0.07	9.2	7.3					
	15 to 16.5								1.75		[a]	14.8	2.72
									1.62		[a]	6.0	2.72
CH-5	20 to 21.5	[b]	663	120	[b]	0.05	5.2	5.4					
	25 to 26.5								1.59		[a]	19.4	2.68
	30 to 31.5	[b]	9,010	2,200	[b]	0.13	7.6	4.8					
	35 to 36.5								1.66		[a]	18.4	2.70
	40 to 41.5	[b]	185	420	[b]	ND	[c]	6.1					
	50 to 51.5	[b]	262	150	[b]	0.26	9.6	7.8					
	60 to 61.5	[b]	1,330	3,000	[b]	0.28	8.2	7					
	70 to 71.5	[b]	7.5	ND	[b]	0.53	5.8	5.3					

Notes: ND = Nondetect

[a] Available upon request from CH2M HILL.
[b] See Appendix U for Results

Groundwater Extraction Wells

Four groundwater extraction wells and seven groundwater monitoring wells were installed by Water Development Corporation with a Dresser T70W Air Rotary Casing Hammer drill rig. Soil samples were logged in general accordance with the Unified Soil Classification System (ASTM D 2488). This drilling method uses threaded drive pipe to keep the borehole open while drilling is accomplished with a tricone bit running slightly ahead of the drive casing. Drill cuttings are brought to the surface by injecting air down the drill pipe and up the annulus between the drill pipe and drive casing. A discharge hose sends cuttings to a cyclone separator where they drop from the separator.

The three deep extraction wells (EW-1C, EW-2C, and EW-3C, Figure D-1) were drilled with a 12-inch-diameter borehole and were completed with 6-inch-diameter Schedule 80 PVC well casing. A 6-inch-diameter stainless steel wire wrap 0.035-inch slot screen with an 8 x 16 sand pack was used. Well construction data are included in Table D-4.

Table D-4
Summary of Groundwater Extraction Construction

Well No.	Elevation TOC (feet msl)	Screened Interval (feet bgs)	Sand Pack Interval (feet bgs)	Casing Diameter (inches)	Screen Slot Size (inches)
EW-1B	28.89	50 to 100	47 to 104	4	0.035
EW-1C	28.74	130 to 140	124 to 141	6	0.035
EW-2C	29.48	78 to 108	72 to 110	6	0.035
EW-3C	28.59	93 to 108	87 to 110	6	0.035

Wells were swabbed during installation of the sand pack to increase settlement of the sand. The sand pack was brought approximately 4 feet above the top of the screen, and No. 30 transition sand seal was installed followed by a bentonite seal. Following hydration of the bentonite seal, cement bentonite grout was tremied to ground surface. Shallow Extraction Well EW-1B was drilled and completed in the same manner except that a 10-inch borehole was used with 4-inch well casing and screen. The wells inside the compound (EW-1B and EW-1C) were completed just belowgrade with surface concrete vaults. The wells outside the compound were completed with above-grade monuments.

All extraction and monitoring wells were developed by bailing, surging, and pumping until clear water was being produced with clarity better than 5 nephelometric turbidity units (NTU) and stable pH, conductivity, and temperature readings.

Cuttings and water produced during drilling were stored onsite in a rolloff bin provided by Delta Oilfield Services of Woodland, California. When soil samples obtained from EW-1C (at 81 and 83 feet bgs) were found to be nonhazardous, cuttings were spread out adjacent to the diesel contaminated soil piles east of the main compound area. Drilling and development water for the four extraction wells was taken to the McClellan Air Force Base (AFB) Industrial Wastewater Treatment Plant.

Observations During Development

Short duration pump tests were conducted during the final stage of development of the extraction wells to estimate aquifer parameters. These estimates will be used to design the long-term aquifer tests required to assess extraction system performance. Water was pumped to a 6,500-gallon storage tank provided by Delta Oilfield Services and was subsequently hauled in 5,000-gallon tank trucks to the McClellan AFB Industrial Wastewater Treatment Plant. A summary of pump test findings is included in Table D-5. In general, most data represents 1 hour of pumping at a constant rate.

Table D-5
Extraction Wells at Davis Global Communications Site

Well No.	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)	Transmissivity (ft^2/day)
EW-1B[ab]	23 68	10 27.5	2.3 2.5	480[a] 460[b] 500[b]
EW-1C[a]	77	4.4	17.5	4,000
EW-2C[a]	76	8.5	8.9	1,900
EW-3C[a]	45	41	1.1	420
MW-19[b] (B aquifer)	40	9.0	4.4	900
MWC-20[b]	41	35.9	1.1	300
MWD-20[b]	40	10.5	3.8	1,000
MWD-21[b]	40	12.7	3.1	830
MWD-22[b]	40	3.12	12.8	3,400
MWE-21[b]	20	1.28	15.6	4,200
MWE-22[b]	40	1.32	30.3	8,100

[a]These wells were analyzed using a method developed by Cooper and Jacob (1946).
[b]These wells were analyzed using a method developed by Driscoll (1986).

Well EW-1B was pumped for 3 hours (180 minutes) at 23 gallons per minute (gpm) on May 11, 1993. After 3 hours of pumping, EW-1B had a total drawdown of 10 feet.

During the pump test, B aquifer Monitoring Wells MW-1, MW-2, MW-3, MW-5, MW-7, and MW-8 were monitored with a Hermit 2000 8-channel data logger. Extraction Well EW-1C, adjacent to Well EW-1B but screened from 130 to 140 feet bgs, was also monitored. Water level data collected at these locations are plotted on Figure D-2. A Cooper-Jacob analysis of the time-drawdown data yielded a transmissivity of 480 ft^2/day in the vicinity of Well EW-1B. All of the monitored wells responded to pumping Well EW-1B with a drawdown in approximate inverse proportion to the distance from the well.

Well EW-1B (screened across the full depth of the B aquifer) produced more water than was anticipated, according to the performance of the monitoring wells in the vicinity. However, those monitoring wells were drilled with hollow-stem augers and have shorter screened intervals. (Drilling through the long intervals of clay strata above the sand zones can result in clay material partially sealing off the productive sand zones and reducing the yield of the well.) Air rotary casing hammer methods combined with thorough development are not likely to have these problems.

An additional test was performed on Well EW-1B at a pumping rate of approximately 68 gpm on May 11, 1993, starting at 9:45 a.m. The same observation wells monitored in the previous test were used to measure drawdown. Drawdown after 1 hour was 27.5 feet in pumping Well EW-1B as measured by hand. All the observation wells had measurable drawdown after 60 minutes of pumping.

A third pump test was performed on Well EW-1C, screened from 130 to 140 feet bgs in a gravelly channel deposit. The well was pumped for 68 minutes at a rate of approximately 77 gpm on May 13, 1993, yielding a maximum drawdown of 4.26 feet. Drawdown was also measured in shallow Monitoring Wells MW-2, MW-3, MW-7, and MWD-2. MWD-2 is located near the eastern compound fence and screened in the same gravelly zone as EW-1C. Drawdown was observed in all the B aquifer observation wells that were monitored. After 68 minutes of pumping, drawdown measured in observation MWD-2 was 3.28 feet. This measurement indicates a broad shallow cone of depression, which is consistent with a zone of high transmissivity. Transmissivity was calculated as 4,000 ft^2/day.

Monitoring Well Installation, Groundwater Sampling, Piezometer Installation, and Hydropunch Sampling

Seven new groundwater Monitoring Wells (MW-19, MWC-20, MWD-20, MWD-21, MWE-21, MWD-22, and MWE-22) and two groundwater Piezometers (PC-21 and PC-22) were drilled and installed in May and June 1993 to improve definition of the horizontal and vertical extent of groundwater contamination. Well completion data are given below in Table D-6.

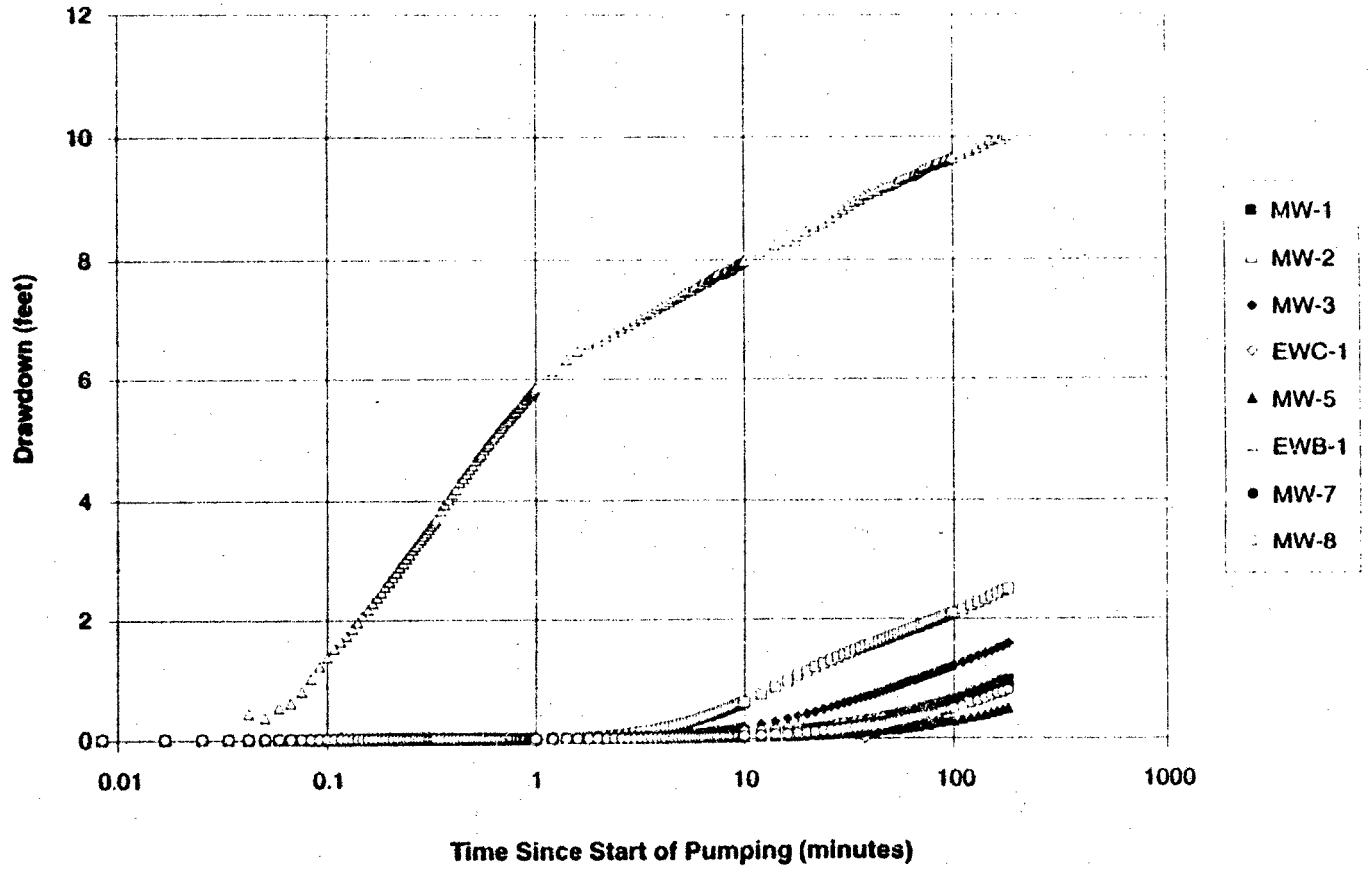


FIGURE D-2
PUMP TEST RESULTS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_208
5055.19

Table D-6 Monitoring Well Construction					
Well No.	Elevation TOC (feet msl)	Screened Interval (feet bgs)	Sand Pack Interval (feet bgs)	Casing Diameter (inches)	Screen Slot Size (inches)
PC-21	27.96	82 to 92	79 to 93	4	0.020
PC-22	28.11	91 to 101	85 to 104	4	0.020
MW-19	25.98	71 to 81	67 to 82	4	0.020
MWC-20	31.75	88 to 108	78 to 110	4	0.020
MWD-20	30.34	143 to 163	135 to 164	5	0.020
MWD-21	29.16	148 to 168	143 to 172	5	0.020
MWE-21	29.92	196 to 216	192 to 222	5	0.020
MWD-22	26.65	147 to 167	140 to 172	5	0.020
MWE-22	26.51	198 to 218	187 to 224	5	0.020

Monitoring Wells MW-19, MWD-20, MWE-21, and MWE-22 were planned to be drilled at locations estimated to be at the edge of the groundwater contamination plume based on available data.

A Hydropunch groundwater sample, HP-2, was taken near MW-19 at a depth of approximately 72 feet bgs and analyzed by CH2M HILL for VOCs. No VOCs were detected; therefore, MW-19 was drilled at the planned location. Two additional attempts were made to collect a C-zone Hydropunch sample (HP-3 at a depth of approximately 100 feet bgs). The first attempt met refusal at 62 feet bgs and the second at 66 feet bgs. Groundwater samples were taken during drilling of MWD-20, MWE-21, and MWE-22 to provide guidance for locations of the remaining monitoring wells. Results are presented in Appendix U.

During drilling of MWE-21, a 220-foot-deep boring south of the compound, a groundwater sample was taken at a depth of 170 feet using the following procedure:

> The drill bit was advanced several feet into a water producing sand and gravel zone, and water was air lifted from the borehole until the water clarity improved. The drill bit and drill pipe were removed and replaced with a submersible pump. The pump was operated for approximately an hour until water quality parameters were stable and clear water was produced. The pump was removed, and a sample was taken from the producing zone using a clean Teflon bailer. This sample was analyzed for volatile organic compounds (VOCs) (Methods 8010/8020) with a 1-day turnaround time by the Central Valley Regional Water Quality Control Board (CVRWQCB) Laboratory in Sacramento, California. The analysis detected 0.3 µg/l, 1,1-dichloroethane; 10.2 µg/l, cis-1,2-dichloroethlene (DCE); 2.9 µg/l, trans-1,2-DCE; and 36.9 µg/l,

trichloroethene (TCE) indicating the groundwater plume had moved at least as far as this well location in the D aquifer.

Drilling on Well MWE-21 continued until a gravel zone was encountered from about 198 to 223 feet. This gravel layer was underlain by clay. A 5-inch-diameter PVC cased well was constructed using 20 feet of stainless steel wire wrap, 0.020-inch slot screen from 198 to 218 feet and an 8 x 20 sand pack. The well was completed in the same manner as the extraction wells. Several wells had a flowing sand condition in the screened interval, which resulted in removal of large volumes of sand and gravel during drilling. In these cases, two to three times the nominal calculated volume of sand pack was used in the screened interval (30 to 40 cubic feet rather than the nominal 13 to 15 cubic feet of sand) to properly sand pack the well. The sand pack was swabbed two or three times in these instances to ensure that it was properly settled.

As a result of the contamination found in the sample from Well MWE-21, Well MWD-21 was drilled 500 feet south of MWE-21 in an attempt to locate the edge of the plume in the D aquifer.

MWE-22A was drilled on the west side of the Site Entrance road. A sample obtained at 160 feet yielded 2.6 μg/l, 1,1-dichloroethene; 1.4 μg/l, cis-1,2-DCE; 2.0 μg/l, toluene; and 11.7 μg/l, TCE using Methods 601/602. After sampling, this borehole was abandoned when the well casing broke above the screen during well installation. The casing was removed, and the remaining borehole was tremie grouted to the ground surface. This abandoned borehole is referred to as MWE-22A. A new well, MWE-22, was relocated further south and east, on the east side of the entrance road.

During drilling of MWE-22, a sample was obtained at 160 feet which yielded no detection of VOCs except 0.1 μg/l of cis-1,2-DCE, using EPA Methods 601/602. Well MWD-22 was drilled adjacent to MWE-22.

During drilling of MWD-20, southwest of the compound, a groundwater sample was obtained from a sand zone at 100 feet. Water from the MWD-20 borehole could not be successfully pumped because of a flowing sand condition which "sand-locked" the pump. The water level was allowed to rise in the drive casing, and a bailed sample was obtained and submitted to the CVRWQCB, which yielded no detection of VOCs using EPA Methods 601/602. Well MWC-20 was drilled adjacent to MWD-20.

The two C aquifers groundwater piezometers, PC-21 and PC-22, were drilled by Water Development Corporation with a CME-75 hollow-stem auger rig. A borehole was drilled with an 8-inch auger and then reamed with a 12-inch auger. A 4-inch Schedule 40 PVC casing was installed inside the 12-inch auger with 10 feet of 0.020-inch slot stainless steel wire wrap screen and an 8 x 20 sand pack.

Cone Penetrometer Soundings and Test Hole

An injection well is proposed near the north edge of the Davis Site due north of the compound and about 300 feet south of County Road 35 (Figure D-3) to dispose of treated groundwater from the proposed groundwater treatment plant. Two CPT soundings, CPT-24 and CPT-25, were advanced by Tonto Drilling of Sacramento, California, at the extraction well locations proposed in the Remedial Design Report. The CPT probe met refusal at 66.44 feet in CPT-24 and at 68.08 feet in CPT-25. In both cases, refusal resulted from excessive friction on the rods in clay, not resistance at the CPT tip. Both CPT holes were advanced in clay or silty clay as noted in the interpretations by Tonto Drilling. CPT logs are presented in Appendix R.

Test Hole 1 (TH-1) was drilled adjacent to CPT-25 by Water Development Corporation, using a CME-85 high-torque auger rig modified to use mud rotary methods. A 6-inch tricone bit was used to drill to 60 feet. The borehole was cored from 60 to 270 feet using a wireline coring system with modified California split-spoon samplers containing brass liners. The core was logged and stored in wax coated cardboard core boxes. Boring and geophysical logs are given in Appendix Q.

Geophysical logging was conducted in Test Hole TH-1 by Welenco of Woodland, California, from ground surface to 255 feet. In spite of the thick drilling mud used, the hole caved between 255 feet and 270 feet in the time it took to remove the drill string and insert the geophysical tool. Resistivity, spontaneous potential, and gamma ray logs were conducted, yielding results consistent with the geologic logs.

Soil samples taken at 104 to 106.5 feet, 203 to 205 feet, and 232 to 236 feet were sent to Mineralogy Incorporated of Tulsa, Oklahoma. The following analyses were performed on the samples to provide design parameters for the reinjection wells:

- X-ray diffraction
- Thin slab core description and photography
- Acid insoluble residue
- Grain size distribution
- Horizontal and vertical porosity
- Air permeability and grain density
- Specific gravity
- Cation exchange capacity
- Scanning electron microscopy
- Energy dispersive x-ray analysis
- Petrographic thin section analysis
- Total organic carbon analysis

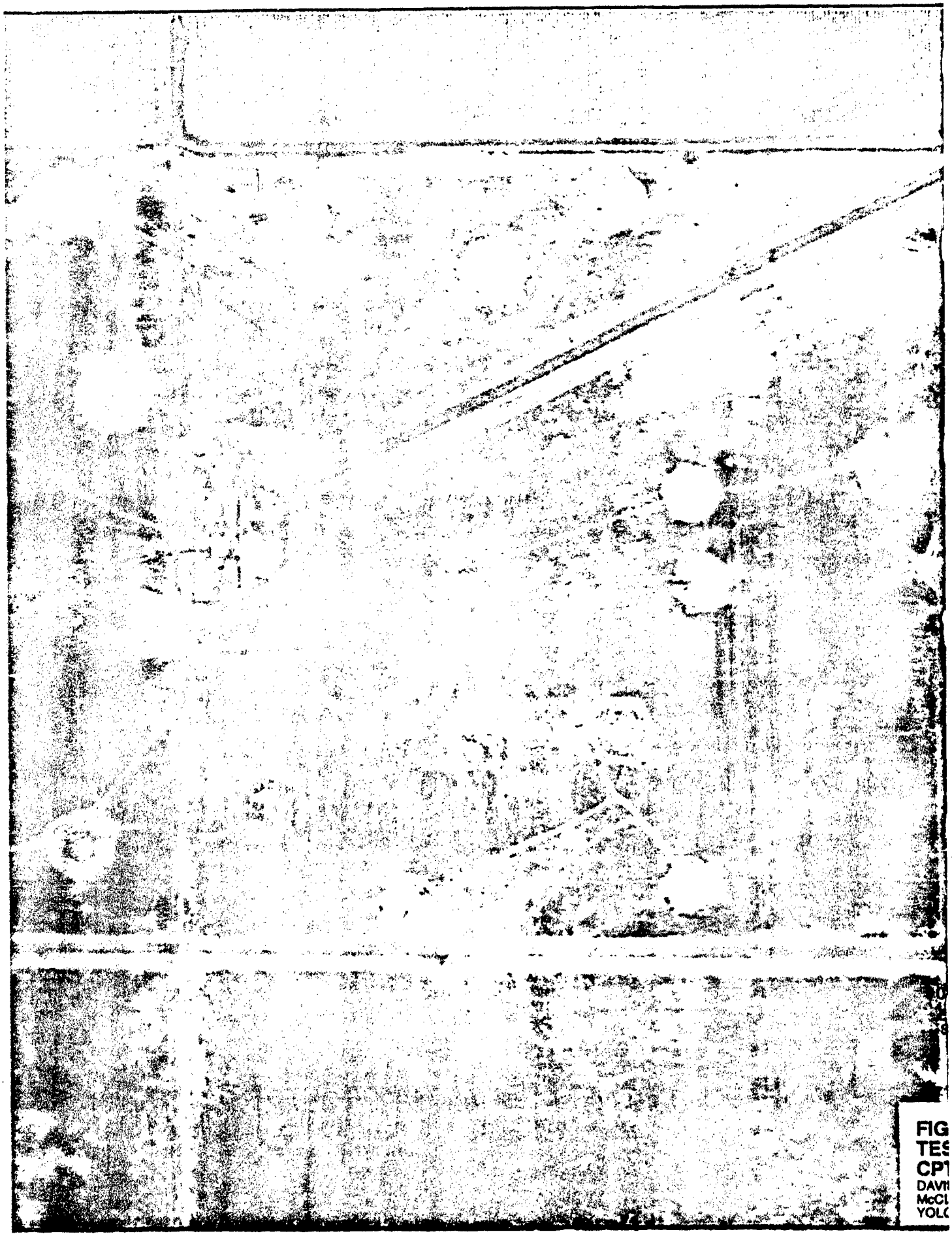


FIG
TES
CP
DAV
McC
YOL

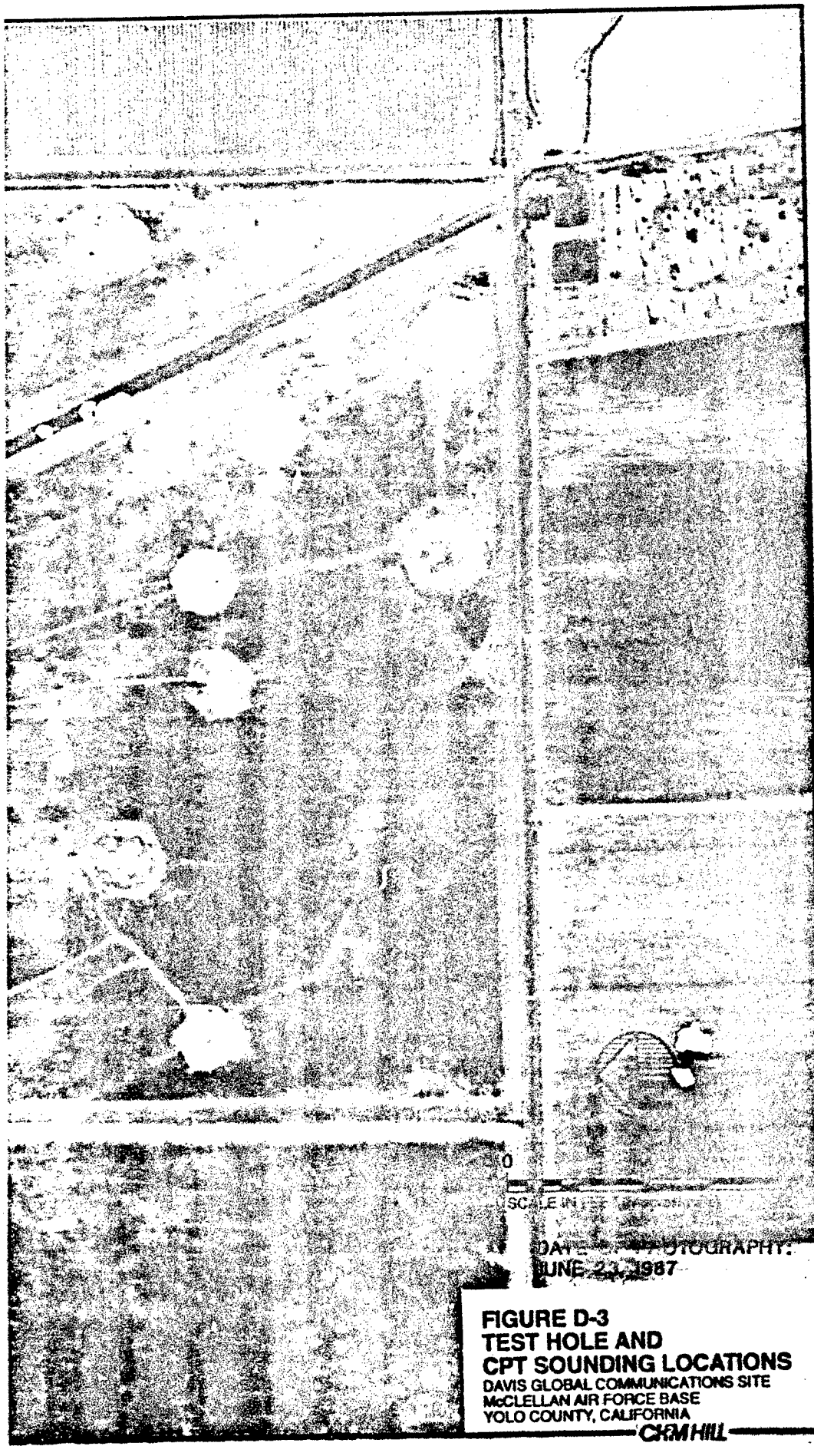


FIGURE D-3
TEST HOLE AND
CPT SOUNDING LOCATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA
CH2M HILL

Attachment D-1, the Mineralogy Incorporated report, is attached at the end of this appendix.

Subsurface Conditions at North Edge of the Site

The subsurface conditions at the north edge of the site is significantly different than in the vicinity of, and south of the compound area. Permeable sandy gravel was encountered between 42 and 46 feet and 52 and 58 feet. Circulation was lost in each zone. Below 58 feet, no permeable zones were encountered until at 98 feet where a silty sand was encountered. This unit became coarser with depth to a well-graded sand from 104 to 108 feet. The interval between 108 to 190 feet consisted of clay and silt. (None of the highly permeable gravel commonly found from 150 to 170 feet near the compound were found at TH-1.) A silty sand was present at 195 feet, which graded to a poorly graded sand at 203 feet and coarsened around 212 feet to a silty gravel. The interval from 215 to 232 feet was primarily silt. A productive gravel zone was encountered from 232 to 263 feet. Core recovery in this zone was very poor because the core barrel blocked off very quickly with pieces of coarse gravel each time a core was attempted. Clay was present again from 263 to 268 feet with sand from 268 feet to the bottom of the borehole at 270 feet.

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Attachment D-1

MINERALOGY
INCORPORATED

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Where Science Gets Down to Earth

July 17, 1993

Gerald Vogt
CH2M Hill
2525 Airpark Drive
Redding CA 96001

SUBJECT

Core analysis results for three selected core intervals from the CH2M Hill Project No. SAC28722.55.10, McClellan AFB-Davis Comm. Site. Mineralogy, Inc. Job No.: 93-327

SUMMARY

The three core intervals submitted for analysis from the McClellan AFB-Davis Comm. Site are representative of an unconsolidated, generally matrix-rich reservoir. Texturally, the core intervals range from fine-grained and well sorted (104-106.5 feet) to bimodally distributed, very poorly sorted sandy pebble conglomerate (232-236 feet). The sandstone cores commonly display fining-upwards cycles, characterized by abrupt (locally erosional) basal contacts, followed by cross-bedded sand capped with parallel laminated, matrix-rich sand and/or clay lamina. Mineralogically, the cores are enriched with respect to lithic rock fragments and contain significant volumes of smectite-rich clay. Storage capacity for the sandstone intervals is excellent (36.8-39.3%), however, air permeability values are low (relative to matrix-poor reservoir sandstones with comparable porosity values). The abundance of pore-filling and grain-coating smectite has resulted in the presence of a significant volume of intercrystalline microporosity and a subsequent reduction in the transmissivity of these reservoir rocks. The large volumes of smectite may contribute to permeability loss and formation damage due to changes in pore fluid salinity and/or clay migration.

INTRODUCTION

Three separate core intervals were submitted for analysis from the CH2M Hill Project No. SAC28722.55.10, McClellan AFB-Davis Comm. Site. A full suite of core analysis tests including: x-ray diffraction, thin slab core description and photography, acid residue analysis, grain size distribution analysis, horizontal and vertical porosity, air permeability and grain density analysis, specific gravity analysis, cation exchange capacity, scanning electron microscopy, energy dispersive x-ray analysis, petrographic thin section analysis, and total organic carbon analysis were performed on representative samples from each of the three core intervals. Due to the disaggregated character of the lowermost core from this well (232.0-236.0 feet), helium porosity, air permeability and grain density measurements were not obtained for this sample.

DISCUSSION OF RESULTS

PAGES 1-3A. THIN SLAB PHOTOGRAPHS AND DESCRIPTIONS

Descriptions of the slabbed core material from each of the three core intervals are presented on Pages 1-3A of this report. The core descriptions are accompanied by photographs of the slabbed core material on each of the three facing pages. The two sandstone core intervals (104-106.5 and 203-205 feet) are characterized by very fine to medium-grained, generally well-sorted, porous, unconsolidated, litharenitic sandstone. Each of the sandstone core intervals displays fining upward cycles ranging from 2-6" in thickness, which reflect a pulse-like depositional history characterized by initial phases of bedload current transport, capped by finely-textured sediments deposited from a combination of suspension and waning bedload transport. The core interval between 203 and 205 feet is characterized by a relatively larger percentage of detrital clay matrix lenses and laminae. Sedimentary structures present within both of the core intervals indicate the presence of low to moderate angle cross-bedded sandstone, with foreset dips ranging between approximately 5 and 30 degrees relative to the horizontal. The localized presence of laminated clay matrix material (especially within the interval between 204 and 205 feet) suggests that vertical permeabilities could be as much as an order of magnitude less for those intervals containing significant amounts of clay within the reservoir.

The disaggregated core material depicted on Page 3A from reservoir depth 232-236 feet is comprised of sandy pebble conglomerate, which lacks any preserved sedimentary structures. The granule and pebble-sized fraction within this core material is admixed with a significant percentage of sandy and silty clay matrix material, which serves as a binding agent within the conglomerate. This sediment is very poorly sorted, bimodally distributed, and enriched with respect to lithic fragments.

TABLE 1. X-RAY MINERALOGY

Results of the x-ray diffraction analysis for each of the three core samples are summarized in Table 1 of this report. Significant mineral constituents present within each of the three core intervals include quartz (61-70%), plagioclase feldspar (8-9%), K-feldspar (2-5%), serpentine (trace-4%), kaolinite (1-2%), and smectite (15-19%). Minor to accessory mineral constituents present within one or more of the core samples include calcite, dolomite, siderite, pyrite, chlorite, and illite/mica.

TABLE 2. ACID INSOLUBLE RESIDUE ANALYSIS

The percentage of acid insoluble residue measured for these core samples in summarized in Table 2 of this report. These results indicate that the percentage of acid insoluble mineral matter present within these samples range between 87.5% and 90.4% of the bulk volume. In light of the x-ray diffraction results reported in Table 1, the acid insoluble residue values indicate that in addition to dissolution of the minor amounts of carbonate cement, the acid solution was effective in dissolving a significant portion of the clay matrix fraction present within these samples.

TABLE 3. GRAIN SIZE DISTRIBUTION ANALYSIS

The results of the grain size distribution analysis for each of the three core samples from this well are included in Table 3 of this report. The two uppermost samples from the reservoir (105.2 and 204.2 feet) are best described as moderately well-sorted, fine-grained sandstone, and very fine-grained sandstone respectively. Each of these two sandstones displays a normal or Gaussian size distribution. The silt and clay fraction within the core sample from depth 105.2 feet accounts for approximately 10.8 weight percent. The silt and clay fraction within the core from depth 204.2 feet accounts for 23.24%. The grain size distribution for the lowermost core sample (235-236 feet) reflects the very poorly sorted, coarse texture of the sandy pebble conglomerate characterizing this interval. Very coarse sand to pebble-size material accounts for approximately 79.39% of the total sample weight. The small volume of silt and clay observed within the grain size analysis of this sediment (1.43%) apparently contradicts the results of the x-ray diffraction analysis and thin section petrography presented for this sample. In partial explanation of this discrepancy, it should be noted that a significant percentage of the clay matrix detected in the x-ray analysis of this sample is present as a primary constituent within many of the pebble to granule-size rock fragments characterizing the mineralogy. Additionally, the relatively small volume of sample material employed in the x-ray diffraction analysis resulted in a sampling bias which favored the more fine-grained matrix material, which is admixed with the pebble to granule-sized clasts from this interval.

TABLE 4. POROSITY, PERMEABILITY AND GRAIN DENSITY ANALYSIS

Results of the helium porosity, air permeability and grain density measurements for horizontal and vertical core plugs from the two uppermost core intervals sampled in this reservoir are presented in Table 4 of this report. As mentioned in the introduction, the coarse texture and disaggregated character of the lowermost core interval (232-236 feet) prevented the successful sampling of this core interval for porosity and permeability determination. Helium porosity values for the core samples from depths 105.3 and 204.3 feet are 39.3% and 36.7% respectively. These porosity values are consistent with experimental porosities obtained for unconsolidated, moderately to well-sorted, loosely-packed sandstone reservoirs. Horizontal permeabilities for these two cores are 141md and 550md respectively. Vertical permeabilities range between 218md and 2115md. The vertical permeability of 2115md reported for sample depth 204.3 feet is artificially high due to the presence of a vertical fracture characterizing the vertical core plug obtained from this sample. In general, the permeability values reported for these core plug samples are fairly low, given the large volume of helium porosity measured. The lower than expected permeability values reflects a significant degree of tortuosity within the intergranular pore network, and is directly attributable to the large volume of clay matrix minerals identified within the sandstones. Grain density measurements for each of the sandstone samples reported in Table 4 is 2.72 g/cc.

TABLE 5. SPECIFIC GRAVITY ANALYSIS

Specific gravity measurements for the three core samples from this well are summarized in Table 5 of this report. Specific gravity values range between 2.29 g/cc though 2.43 g/cc. The core sample from depth 105.2 feet displays the highest specific gravity value observed (2.43 g/cc , reflecting the presence of minor amounts of siderite and pyrite within sandstone.

TABLE 6. CATION EXCHANGE CAPACITY

The summary of the cation exchange capacity analysis is provided in Table 6 of this report. CEC values for these sandstones range between 3.38 and 11.20 meq/Na 100g of core. These values are consistent with sediments containing significant volumes of smectite-rich clay matrix material. The core sample from depth 204.1 feet displays the highest CEC value of 11.20 meq/Na 100g. This maximum is consistent with the x-ray mineralogy for this sandstone, given the large volume of smectite-rich clay matrix identified for this interval (24% total matrix; see Table 1).

TABLE 7. TOTAL ORGANIC CARBON ANALYSIS

The percentage of total organic carbon measured for each of the three core intervals is reported in Table 7 of this report. The percentage of organic carbon ranges between 0.06% and 0.12%. The

uppermost core at 105.2 feet displays the largest percentage of organic carbon which accounts for 0.12% of the bulk volume within this sample.

FIGURES 1-3. SEM ANALYSIS

Results of the SEM analysis are presented in Figure plates 1-3, together with the associated descriptive captions for each sample. The SEM analysis of these sandstones indicates that these core samples are comprised of unconsolidated, loosely-packed, matrix-rich, litharenitic sandstone. The uppermost cores, at depths 105.3 and 204.2 feet respectively, are characterized by moderately well sorted to well sorted detrital frameworks, which contain an abundance of pore-filling and grain-coating smectite-rich clay matrix material. The disaggregated sample from depth 235-236 feet is characterized by a very poorly-sorted mixture of granules and pebbles, admixed with intersticial silt and smectite-rich clay matrix. The clay matrix present within this sample serves as a binding agent for the finer-grained sand and silt fraction. The abundance of smectite-rich clay matrix within each of the three core intervals indicates that significant reservoir management problems could result from induced fluid flow and/or pore fluid salinity changes within the reservoir. The widespread presence of smectite is likely to result in swelling and partial to complete closure of intergranular pore throats upon exposure of the formation to fresh water. The loosely-attached character of the pore-filling clay matrix additionally suggests that clay migration is likely to accompany enhanced production and/or injection rates within this reservoir.

FIGURES 4-9. THIN SECTION ANALYSIS

Summaries of the petrographic analysis for each of the three core samples from this reservoir are provided on the individual thin section descriptions with representative photomicrographs presented in Figures 4-9 of this report. The two sandstone samples from this well (105.3 and 204.2 feet) are characterized as unconsolidated, porous, fine-grained, well-sorted, matrix-rich, litharenitic sandstones. These core intervals are loosely packed, and display a predominance of point-to-point intergranular contacts, with scattered patches of pseudomatrix derived from mechanically squashed ductile rock fragments. Mineralogically, the two sandstone samples are similar, and contain a predominance of monocrystalline quartz, metamorphic rock fragments, volcanic rock fragments, feldspar (plagioclase and K-feldspar), polycrystalline quartz, and chert. Clay matrix components are relatively more abundant within the sample from depth 204.2 feet. The clay fraction is dominated by smectite within both of the sandstone samples, which occurs as diffuse clusters of pore-filling clay matrix, as well as grain-coating authigenic clay. Much of the pore-filling clay matrix is interpreted as infiltrated detrital clay, which was introduced into these sandstones shortly following deposition. Some authigenic clay matrix has been derived due to the partial to complete dissolution and replacement of chemically

metastable rock fragments and feldspar grains. Macro pore volumes within these two sandstones are visually estimated to range between approximately 23 and 26% of the bulk volume. The predominant macro pore type is intergranular porosity, with minor amounts of intragranular dissolution porosity present in association with the partially leached feldspar grains and rock fragments. Intercrystalline micro porosity is significant within both sandstones in association with the clusters of diffuse pore-filling clay matrix material. The clay matrix has contributed to a highly torturous flow network within each of the sandstone samples, resulting in lowered permeabilities for these unconsolidated sand intervals.

The disaggregated core sample from depth 235-236 feet is characterized as a matrix-rich, sandy pebble conglomerate. The thin section sample indicates a bimodally-distributed texture characterized by coarse sand to pebble-sized grains admixed with silty and sandy clay matrix material. Detrital components include quartz, volcanic rock fragments, metamorphic rock fragments, feldspar (plagioclase and K-feldspar), sedimentary sandstone rock fragments, and chert. Thin section porosity estimates are meaningless for this sample, given the absence of an undisturbed detrital framework. The abundance of smectite-rich clay matrix material apparent in the thin section sample suggests that permeability for this reservoir interval is unlikely to exceed the values for the two sandstone samples reported in Table 4.

ENERGY DISPERSIVE CHEMICAL ANALYSIS (EDX)

Energy dispersive x-ray analysis of the three core intervals indicates that silicon (Si) is the most abundant elemental constituent (74.3-86.6%). The core samples are also characterized by significant amounts of iron (Fe), which ranges between 10.6 and 18.4%. Minor elemental constituents include potassium (0.3-2.1%), calcium (0.8-6.2%), and titanium (0.1-0.9%). It should be noted that each of the core samples from this well contain significant amounts of aluminum, as indicated by the asymmetric left flank of the silicon peaks on each of the three energy dispersive spectra. The close spacing of the energy dispersive spectral lines for these two elements precludes the accurate estimation of aluminum volumes within these samples.

The conditions under which this report is presented are described immediately following this report. It is our hope that these results will prove useful in the successful development and management of this reservoir. If you should have questions regarding this report, or if we can be of further service, please don't hesitate to call.

Sincerely,

Timothy B. Murphy, President
Mineralogy, Inc.

II. CONDITIONS AND QUALIFICATIONS

Mineralogy, Inc. will endeavor to provide accurate and reliable laboratory measurements of the samples provided by the client. The results of any x-ray diffraction, petrographic or core analysis test are necessarily influenced by the condition and selection of the samples to be analyzed. It should be recognized that mineralogical samples are commonly heterogeneous and lack uniform properties. Unless otherwise directed, the samples selected for analysis will be chosen to reflect a visually representative portion of the bulk sample submitted for analysis. Where provided, the interpretation of x-ray diffraction, petrographic or core analysis results constitutes the best geological judgement of Mineralogy, Inc., and is subject to the sampling limitations described above, and detection limits inherent to semi-quantitative mineralogical analysis. Mineralogy, Inc. assumes no responsibility nor offers any guarantee of the productivity or performance of any oil or gas well or hydrocarbon recovery process, based upon the data presented in this report.

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Energy Dispersive Elemental Analysis	

CORE SLAB DESCRIPTION

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

104.0-106.5 feet

104.0-104.8 feet Very fine to fine-grained (vfU-fL), very well-sorted, porous, litharenitic sandstone. The interval displays low angle cross-bedding (inclined at approximately 5-20 degrees relative to the horizontal). The mean grain diameter is approximately 125 microns. The interval is mildly compacted and unconsolidated. This subinterval completes a fining upward cycle whose base is located at approximately 105.15 feet. The interval displays a gradational basal contact.

104.8-105.15 feet Medium-grained (mL to mU), well-sorted, porous, litharenitic sandstone. This sand interval is mildly compacted and unconsolidated. The unit fines upward and is gradationally overlain by the very fine-grained sand interval described above (104.0-104.8 feet). The sandstone is cross-bedded, and displays foreset dips of approximately 20-30 degrees relative to the horizontal. The interval displays a gradational basal contact.

105.15-105.5 feet Medium to very fine-grained (mL to vfU), fining-upwards, well-sorted, rounded, porous, unconsolidated, litharenitic sandstone. This interval is locally matrix rich, with the percentage of pore-filling clay matrix increasing within the upper one-half of the unit. The sedimentary structures present within the interval grade from low angle cross-bedding at the base to parallel-bedded sand within the upper one-half of the subinterval.

105.5-106.0 feet Missing

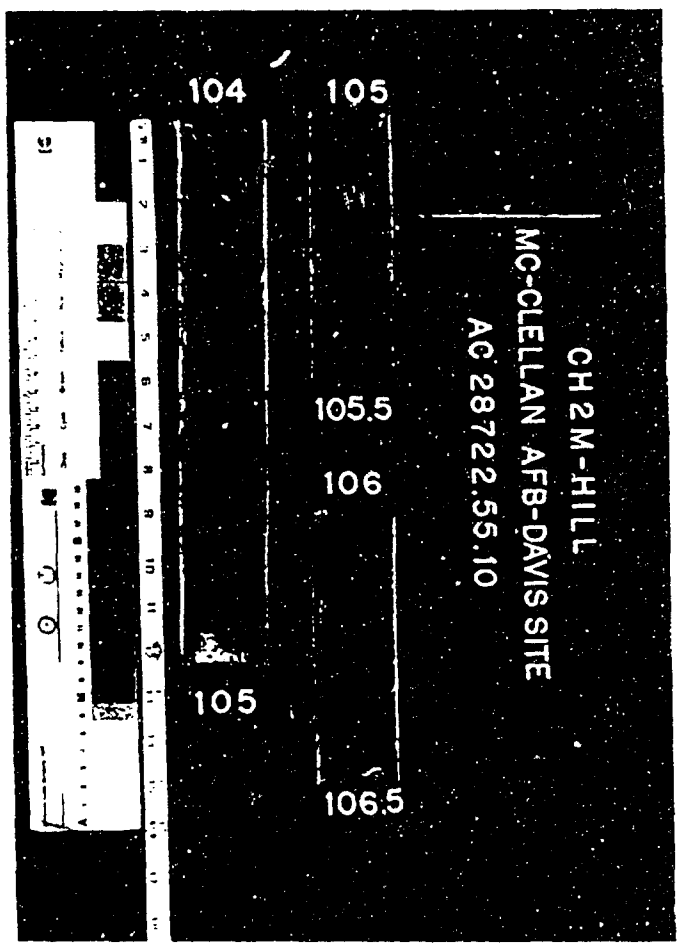
106.0-106.5 feet Very fine to medium-grained (vfU to mU), moderately-sorted, rounded, locally matrix-laminated, unconsolidated, litharenitic sandstone. The interval is cross-bedded, and displays foreset dips ranging between 15 and 25 degrees relative to the horizontal. A disturbed matrix laminae is present at approximately 106.2 feet. The interval is matrix rich between 106.2 and 106.5 feet, and is characterized by lenses and laminae of detrital clay matrix. The layer of medium-grained sand present between 106.0 and 106.2 feet appears to be porous and permeable.

PAGE 1A.

CORE SLAB PHOTOGRAPH

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

104.0-106.5 feet



CORE SLAB DESCRIPTION

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

203.0-205.0 feet

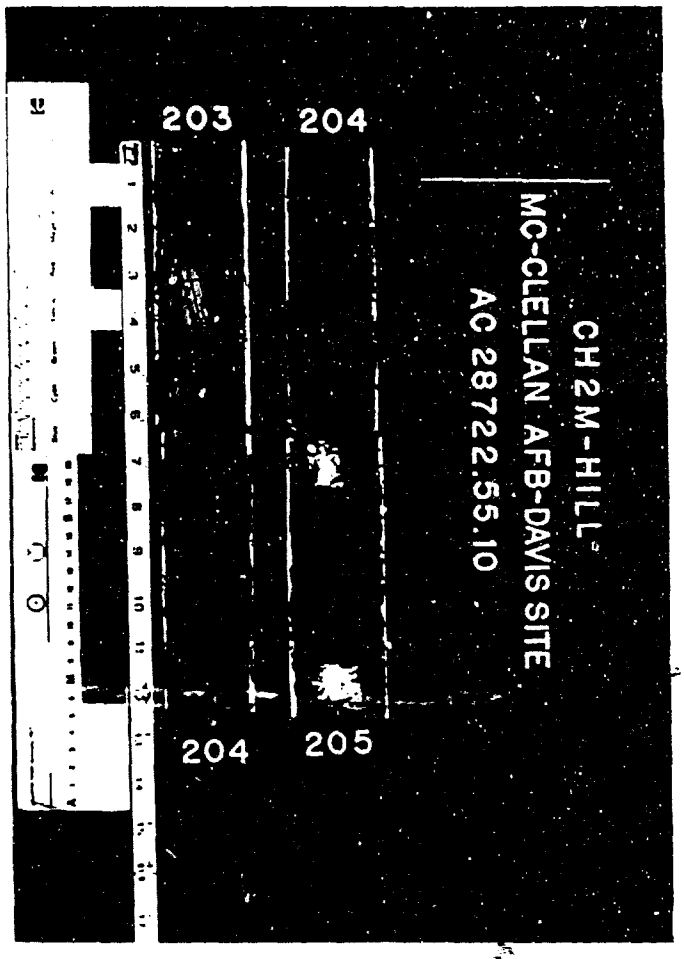
203.0-205.0 feet Very fine to fine-grained (vfU to fU), well-sorted, fining-upwards, unconsolidated, locally matrix-laminated, litharenitic sandstone. Fining upward cycles are present between 203.2 thru 203.5 feet, 203.5 thru 203.75 feet, 203.75 thru 204.5 feet, and 204.5 thru 205.0 feet. Each of these cycles is capped by thin laminae (approximately 3-10mm thick) of silty matrix material. The cycles display sharp (erosional) basal contacts. The unit is porous, mildly compacted, and unconsolidated. Sedimentary structures include low angle cross-bedding (with foreset dips ranging between 5 and 15 degrees relative to horizontal), which grade into parallel-bedded sandstone and siltstone near the top of the fining upward cycles. Vertical permeability across the matrix laminae is likely to be very low.

PAGE 2A.

CORE SLAB PHOTOGRAPH

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

203.0-205.0 feet



CORE SLAB DESCRIPTION

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

232.0-236.0 feet

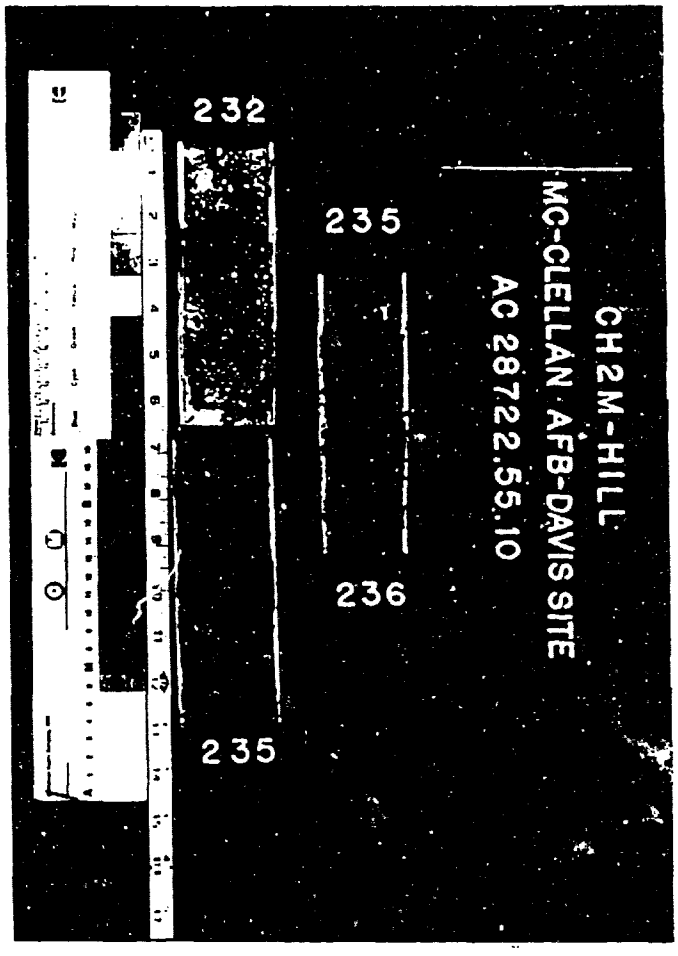
232.0-236.0 feet This interval is comprised of matrix-rich, sandy pebble conglomerate, which was collected as loore sediment at the well site. As such, there are no preserved sedimentary structures or meaningful texture relationships which can be derived from this sample. Mineralogically, the pebbles are comprised of volcanic and metamorphic rock fragments, as well as scattered chert clasts and polycrystalline quartz fragments. The pebbles and granules are separated by a significant percentage of very fine-grained sand, silt, and clay matrix material, which is ubiquitous within the core interval. The abundance of clay matrix, as well as the very poorly-sorted character of the sediment from this interval, suggests that permeabilities for this portion of the reservoir are likely to be low.

PAGE 3A.

CORE SLAB PHOTOGRAPH

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

232.0-236.0 feet



Job 93-327

TABLE 1.

MINERALOGY, INC.

3228 E 15th St
Tulsa Oklahoma 74104

X-RAY DIFFRACTION MINERAL PERCENTAGES

SAMPLE IDENTIFICATION NUMBER CH2M HILL Proj. SAC28722.55.10	QUARTZ	PLAGICLASE FELDSPAR	K-FELDSPAR	CALCITE	DOLOMITE	SIDERITE	PYRITE	SERPENTINE	KAOLINITE	CHLORITE	ILLITE/MICA	SMECTITE								TOTAL
105.2 feet	70	8	3	trc	trc	1	1	trc	2			15								
204.2 feet	61	8	5	trc	trc		trc	2	2	2	1	19								
235-236 feet	64	9	2	trc	1			4	1	trc	1	18								

TABLE 2.

ACID INSOLUBLE RESIDUE ANALYSIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Depth (feet)	% Acid Insoluble
105.2	87.5%
204.2	88.3%
235-236	90.4%

TABLE 3.

GRAIN SIZE DISTRIBUTION ANALYSIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Depth: 105.2 feet

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule	0%
<2.00 >1.00	Very Coarse Sand	.31%
<1.00 >0.50	Coarse Sand	9.23%
<0.50 >0.25	Medium Sand	26.60%
<0.25 >0.125	Fine Sand	36.73%
<0.125 >0.0625	Very Fine Sand	16.33%
<0.0625	Silt and Clay	10.80%

Depth: 204.2 feet

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule	0%
<2.00 >1.00	Very Coarse Sand	.02%
<1.00 >0.50	Coarse Sand	.81%
<0.50 >0.25	Medium Sand	9.11%
<0.25 >0.125	Fine Sand	25.20%
<0.125 >0.0625	Very Fine Sand	41.62%
<0.0625	Silt and Clay	23.24%

Depth: 235-236 feet

Sieve Size (mm)	Description	Weight Percent
>2.00	Pebble/Granule	56.95%
<2.00 >1.00	Very Coarse Sand	22.44%
<1.00 >0.50	Coarse Sand	9.16%
<0.50 >0.25	Medium Sand	5.03%
<0.25 >0.125	Fine Sand	2.72%
<0.125 >0.0625	Very Fine Sand	2.27%
<0.0625	Silt and Clay	1.43%

TABLE 4.

3228 E. 15th St.
Tulsa, Oklahoma 74104

M. I.
MINERALOGY, INC.

918 744-8264

Lab No. 93-327
Date

ell Proj. SAC28722.55.10 Field McClellan AFB-Davis State

mple mber	Depth	Description	Permeability-md Horiz.	Permeability-md Vert.	Porosity %	Saturation - % PV Oil	Saturation - % PV Water	Grain Density gm/cc
1	105.3'		141.	218.	39.3			2.72
2	204.3'	(vert. Fr.)	550.	2115.	36.7			2.72

TABLE 5.

SPECIFIC GRAVITY ANALYSIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Depth	Specific Gravity
105.2 feet	2.43
204.2 feet	2.34
235-236 feet	2.29

TABLE 6.

CATION EXCHANGE CAPACITY

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Depth	CEC (meq Na/100g)
105.1 feet	6.43
204.1 feet	11.20
235-236 feet	3.38

TABLE 7.

TOTAL ORGANIC CARBON ANALYSIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Depth	% ORGANIC CARBON
105.2 feet	.12%
204.2 feet	.06%
235-236 feet	.08%

FIGURE 1.

CH2M HILL
Project No. SAC28722.55.10; McClellan AFB-Davis Comm. Site

105.3 feet

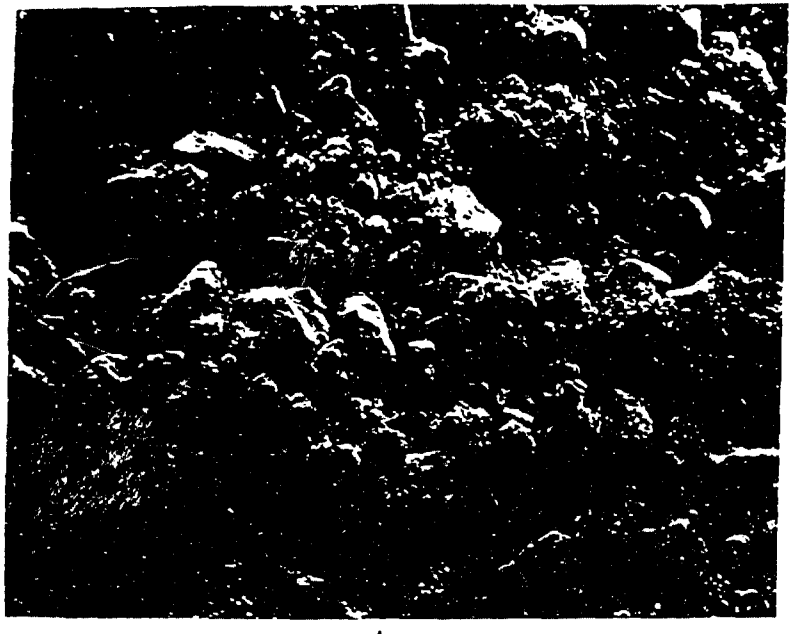
A&B Low magnification views illustrating the fine-grained, well-sorted, and locally matrix-rich character of this unconsolidated litharenitic sandstone. Although intergranular macro porosity is apparent and abundant throughout these two photomicrographs, the abundance of pore-filling clay matrix admixed with very fine silt and sand within the pore spaces suggests that permeability for this interval could be relatively low.

C&D Detailed views of a cluster of pore-filling smectite matrix material. The horizontal lines distorting the field of view in Figure 1D are the result of electrostatic charging, which is related to the abundance of loosely-attached clay platelets and particles within the SEM sample prepared from this unconsolidated sample.

Magnifications:

1A - 60X
1B - 150X
1C - 500X
1D - 1150X

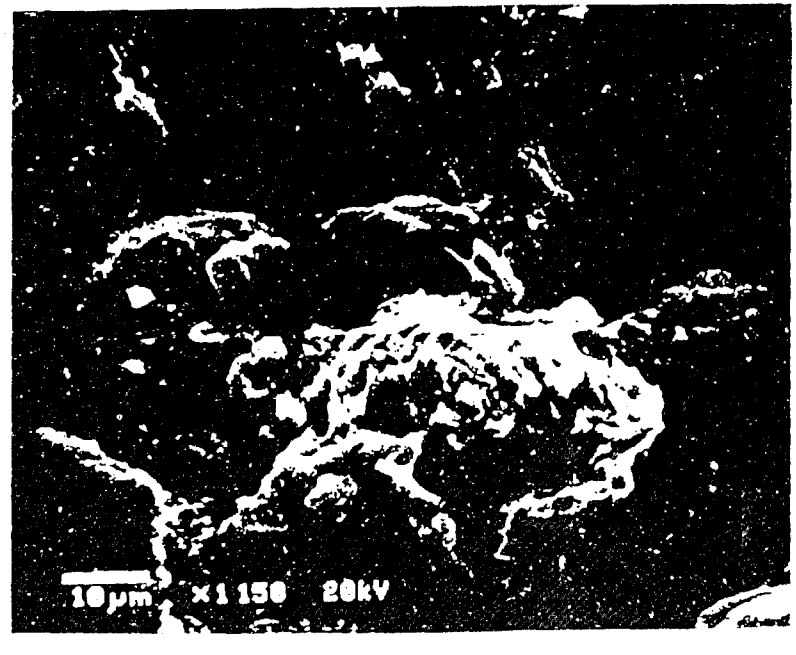
CH2M HILL; PROJECT NO. 28722.55.10; McCLELLAN AFB-DAVIS COMM. SITE; SAMPLE DEPTH 105.5 feet



A

B

C



D

Figure 1.

FIGURE 2.

CH2M HILL
Project No. SAC28722.55.10; McClellan AFB-Davis Comm. Site

204.2 feet

A&B Low magnification views of this porous, well-sorted, fine-grained, unconsolidated, litharenitic sandstone. Note the abundance of pore-filling and grain-coating clay matrix apparent in Figure 2B (center).

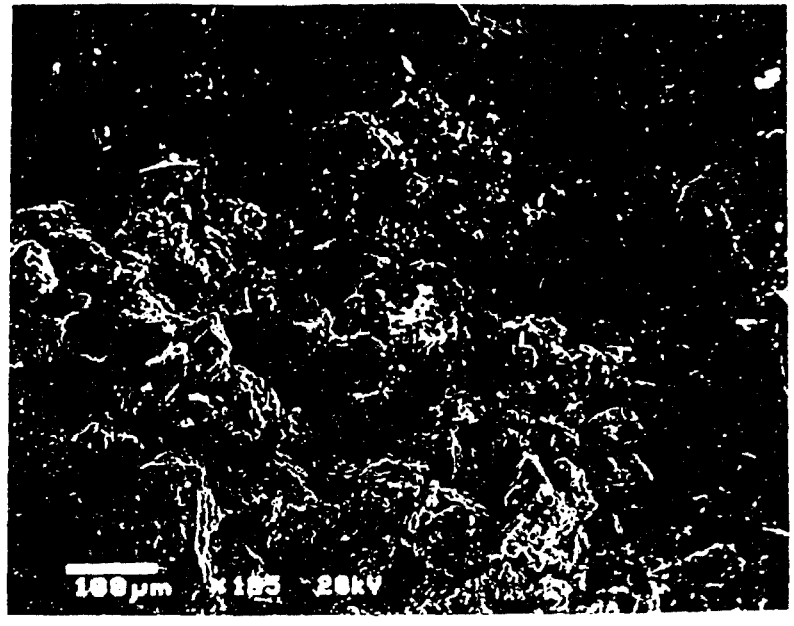
C&D Detailed views of a cluster of authigenic smectite, which has partially obstructed an intergranular pore throat (center; Figure 2C). The smectite is apparently draped with traces of fibrous illite matrix material as illustrated in the central portion of Figure 2D.

Magnifications:

2A - 40X
2B - 125X
2C - 500X
2D - 1000X

CH2M HILL; PROJECT NO. 287.2.55.10; [illegible] SAMPLE DEPTH 204.2 FEET

A



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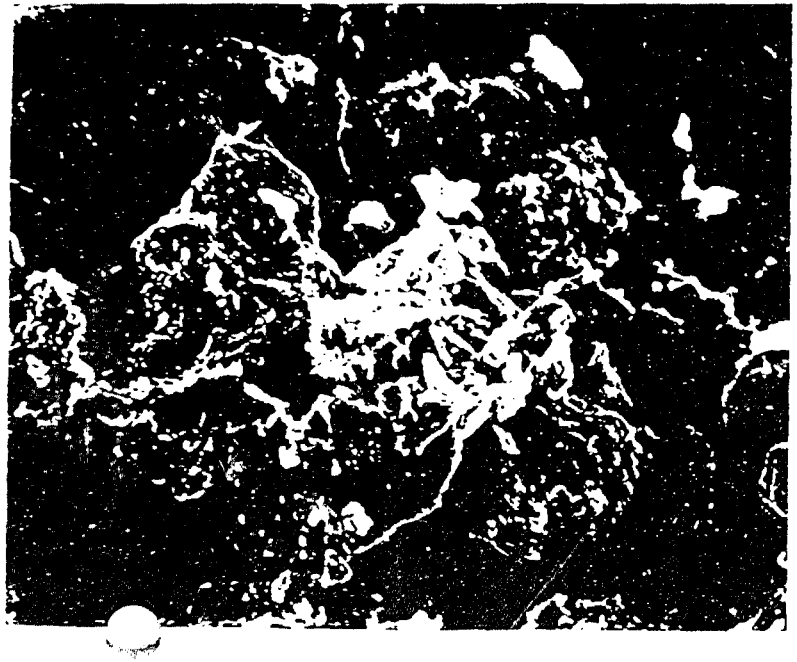

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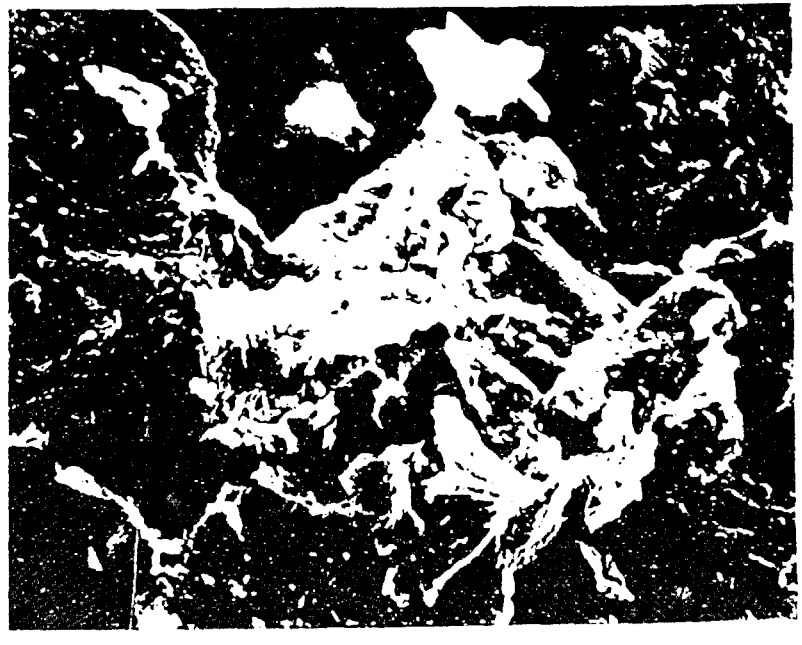

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Figure 2.

FIGURE 3.

CH2M HILL
Project No. SAC28722.55.10; McClellan AFB-Davis Comm. Site

235-236 feet

A&B Low magnification views of this artificially-packed, unconsolidated, very poorly-sorted, sandy pebble conglomerate. Note how the smectite-rich clay matrix material drapes the pebble surface in the right-central portion of Figure 3A. Smectite-rich clay matrix material, as illustrated in the central portion of Figure 3B, is responsible for loosely binding the silt and sand grains present between the pebbles within this disaggregated core sample.

C&D Detailed views of the authigenic clay matrix material which coats the detrital grain surfaces and fills many of the intergranular pores within this sediment. The crenulated appearance of the matrix edges apparent in the bottom-central portion of Figure 3D is characteristic of smectite clay.

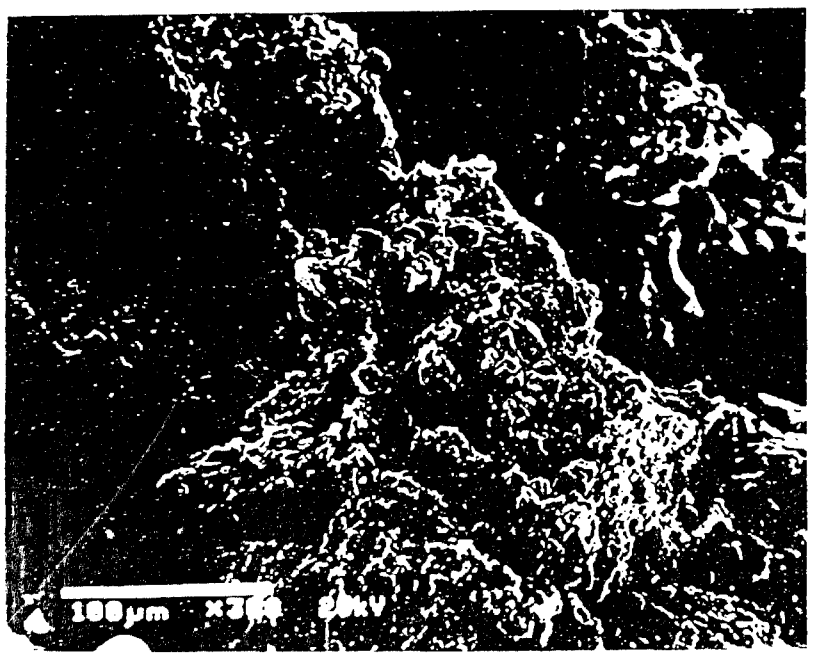
Magnifications:

3A - 35X
3B - 125X
3C - 300X
3D - 880X

CH2M HILL; PROJECT NO. 28722.55.10; McCLELLAN AFB-DAVIS COMM. SITE; SAMPLE DEPTH 235-236 feet

A

B



C

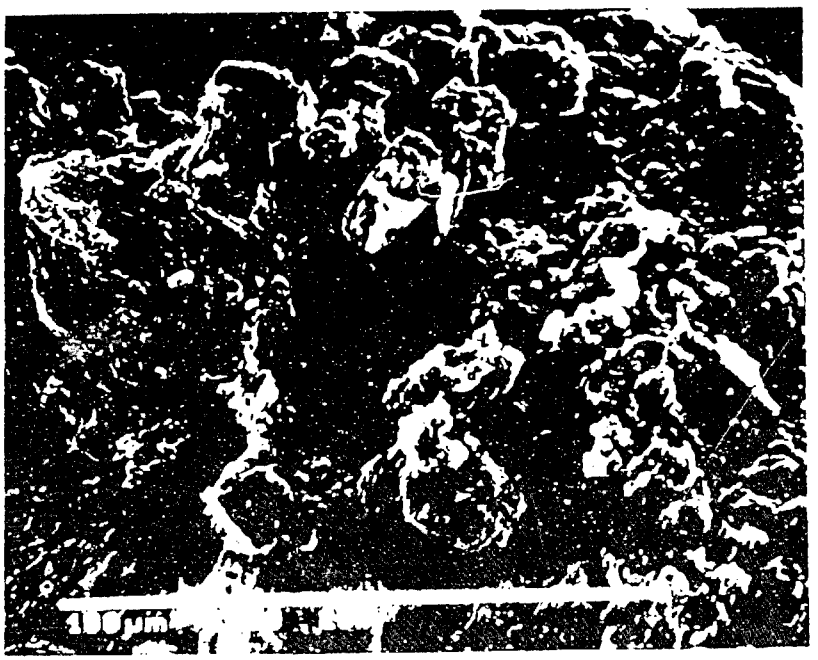


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Figure 3.

THIN SECTION DESCRIPTION

CH2M HILL
Project No. SAC28722.55.10; McClellan AFB-Davis Comm. Site

105.3 feet

This core interval is comprised of porous, fine-grained (fL), very well-sorted, rounded, unconsolidated, litharenitic sandstone. The mean grain diameter is approximately 0.15mm, with a maximum grain diameter of 1.24mm. The sandstone is mildly compacted, and displays a predominance of point-to-point intergranular contacts, together with minor amounts of pseudomatrix. The detrital composition is dominated by monocrystalline quartz, together with metamorphic rock fragments (mostly schist, phyllite, and slate fragments), volcanic rock fragments, plagioclase feldspar, K-feldspar, polycrystalline quartz, and chert. Minor to accessory grain varieties include glauconite, amphibole, pyroxene, and mica. Several of the metamorphic rock fragments contain serpentine. Clay matrix constituents are moderately abundant within the sample, occurring as pore-filling, pore-lining, and grain-replacing components. Smectite is the dominant clay variety. Clusters of micro porous, pore-filling smectite are common within the sample, and were probably derived as infiltrated clay matrix from overlying sedimentary units. Metamorphic rock fragments, volcanic rock fragments, feldspar, pyroxene, and amphibole are all locally subject to replacement with smectite matrix. Pore-lining smectite is widely distributed as an encrustation on the detrital grain surfaces. Kaolinite is present as a minor clay variety, as identified via x-ray diffraction analysis. Cement varieties identified within the sample include minor amounts of siderite and pyrite, which are irregularly distributed as subhedral to anhedral crystalline masses, which have partially to completely replaced scattered detrital grains within this sandstone. Some goethite is also present as a replacement within iron-rich detrital grains. The macro pore volume is visually estimated to account for approximately 26% of the bulk volume. The macro pore volume is dominated by intergranular porosity, together with minor amounts of secondary intragranular dissolution porosity. Micro porosity is common throughout the sandstone, and is present in association with the scattered clusters of pore-filling clay matrix, as well as within matrix-replaced detrital grains. Relative to the storage capacity, the permeability of this sandstone is likely to be low, given the widespread presence and abundance of pore-filling and pore-lining clay matrix minerals. The abundance of smectite within the pore network is likely to adversely affect fluid transmissivity within this reservoir. Smectite is highly prone to swelling in the presence of fresh water, and could significantly limit fluid transmissivity due to obstruction and ultimate blockage of the intergranular pore throats.

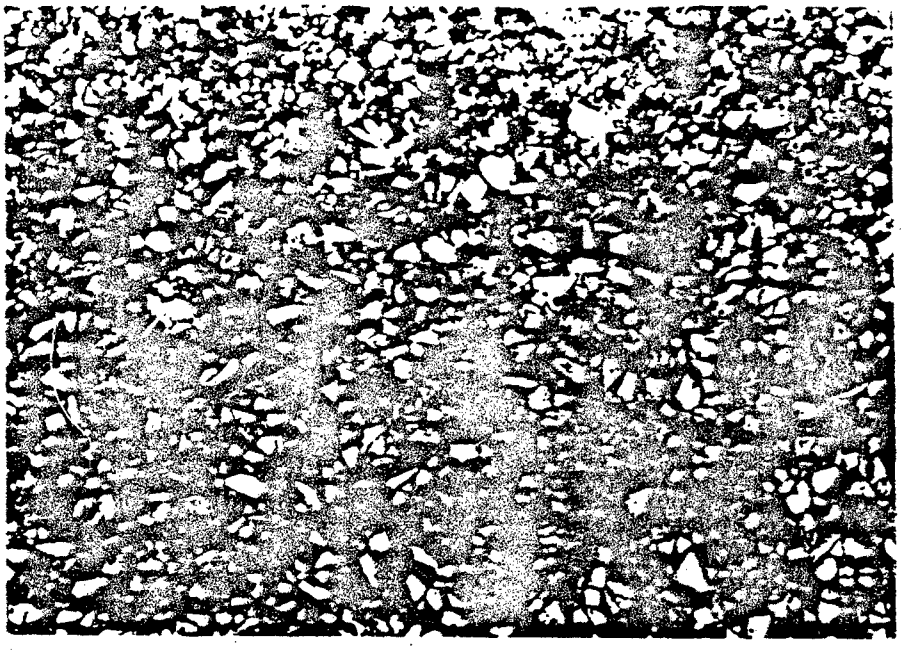


Figure 4. A low magnification view of this porous, fine-grained (fL), very well-sorted, unconsolidated, litharenitic sandstone. 15X 1.2"=2.0mm uncrossed nicols

CH2M HILL; Project SAC28722.55.10; McClellan AFB-Davis
105.3 feet

Figure 5. This photomicrograph provides a detailed view of a leached detrital grain which has been partially replaced with diffuse clay matrix minerals (smectite; center). 100X 1"=0.25mm uncrossed nicols

THIN SECTION DESCRIPTION

CH2M HILL
Project No. SAC28722.55.10; McClellan AFB-Davis Comm. Site

204.2 feet

The core sample from this interval is comprised of porous, well-sorted, subrounded, unconsolidated, matrix-rich, litharenitic sandstone. The sandstone is fine-grained (fU), and displays a mean grain diameter of approximately 0.17mm, with a maximum grain diameter of 1.04mm. The detrital fabric is mildly compacted, and displays a predominance of point-to-point intergranular contacts, with scattered patches of pseudomatrix generated by mechanically deformed and squashed ductile rock fragments. The detrital framework is comprised of a combination of monocrystalline quartz, metamorphic rock fragments (schist, phyllite, and slate fragments), volcanic rock fragments, plagioclase feldspar, K-feldspar, polycrystalline quartz, and chert. Minor to accessory detrital components include glauconite, pyroxene, amphibole, epidote, and mica. A large percentage of the metamorphic rock fragments are enriched with respect to clay matrix minerals, and several display serpentine/antigorite-rich mineralogies. The matrix fraction is comprised of detrital and authigenic clay matrix, which is dominated by smectite. The authigenic clay matrix is present as a pore-lining and grain-replacing constituent, whereas the detrital clay matrix is present as clusters of loosely-packed pore-filling clay, which is believed to have been infiltrated from overlying sedimentary layers. Matrix-replaced detrital grains include metamorphic rock fragments, volcanic rock fragments, pyroxene, amphibole, and feldspar. Minor to accessory clay varieties include kaolinite, chlorite, and illite. The pore volume is comprised of a combination of macro porosity and intercrystalline micro porosity. The macro pore volume consists of intergranular voids, together with minor amounts of intragranular secondary dissolution porosity. The macro pore volume is visually estimated to account for approximately 23% of the bulk volume. Secondary intragranular pores are largely present due to the partial to complete dissolution of detrital feldspar grains and rock fragments. Intercrystalline micro porosity is abundant within the sample, and is present in association with the clusters of pore-filling clay matrix minerals. The permeability of this interval of the reservoir is expected to be moderate to low, given the ubiquitous presence of pore-filling and pore-lining clays.

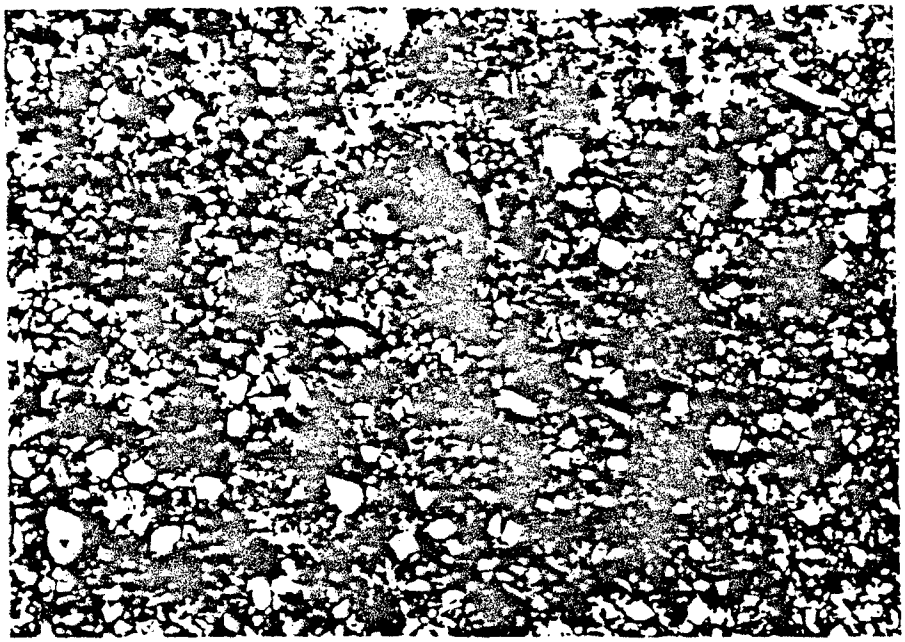
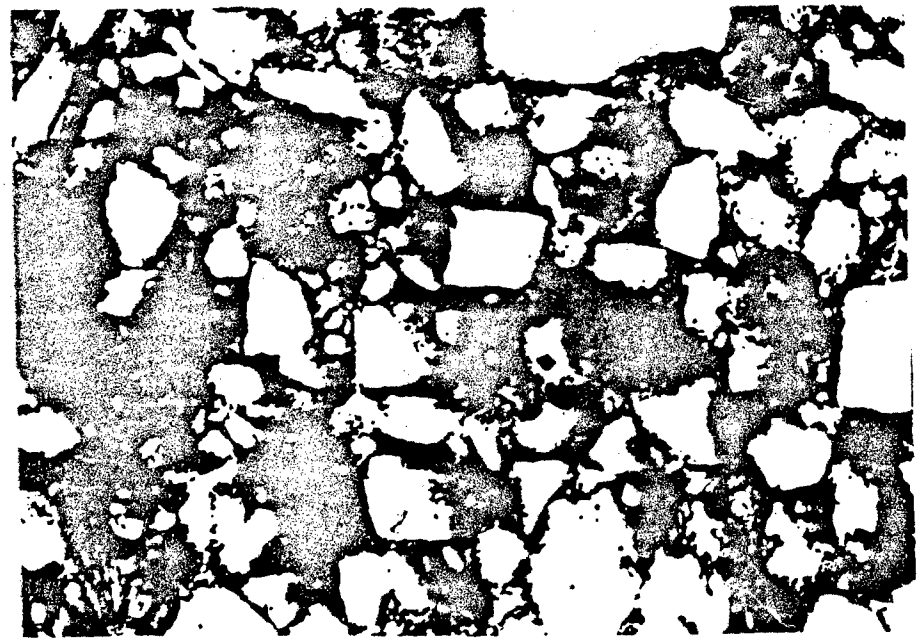


Figure 6. A low magnification view of this porous, fine-grained (fL), well-sorted, unconsolidated, litharenitic sandstone. Note the abundance of pore-filling clay matrix distributed throughout this field of view (olive green to gray). 15X 1.2"=2.0mm uncrossed nicols

CH2M HILL; Project SAC28722.55.10; McClellan AFB-Davis
204.2 feet

Figure 7. Pore-filling detrital clay matrix (smectite) is nearly ubiquitous throughout the framework of this sandstone. Note the tan-colored, carbonate-replaced grain present in the lower left-hand corner of this photomicrograph. 100X 1"=0.25mm uncrossed nicols



THIN SECTION DESCRIPTION

CH2M HILL
Project No. SAC28722.55.10; McClellan AFB-Davis Comm. Site

235-236 feet

The core material collected from this interval of the reservoir was disturbed and disaggregated at the well site. The representative thin section of the disaggregated core from this interval was prepared and is described as follows: the core material is very poorly-sorted, unconsolidated, litharenitic, matrix-rich, sandy pebble conglomerate. Texturally, this sample is bimodally distributed, and displays a pebble fraction with a mean grain diameter of approximately 2.95mm, and a maximum grain diameter of 7.48mm. The fine grain fraction of the sediment is represented by a mixture of sand, silt, and clay matrix separating the pebbles of the conglomerate. Texturally, this material is best described as matrix-rich, very fine-grained sand to coarse silt-sized, with an average grain diameter of approximately 0.065mm. The disaggregated nature of the sediment precludes a meaningful description of the packing configuration for this interval of the reservoir. The pebbles and granules are suspended in a sandy and silty clay-rich matrix throughout the thin section sample. The detrital framework is comprised of a combination of quartz, volcanic rock fragments, metamorphic rock fragments, plagioclase feldspar, K-feldspar, sedimentary rock fragments (sandstone), and chert. Minor to accessory detrital constituents include traces of pyroxene, amphibole, and mica. Detrital clay matrix is ubiquitous as a pore-filling constituent, and is admixed with silt and sand. Smectite is the predominant matrix variety, with minor amounts of kaolinite and illite also present. Minor to trace amounts of authigenic clay matrix are present as replacements within the leached and altered volcanic rock fragments, metamorphic rock fragments, and feldspar. Pore space present within the thin section sample is artificial due to the disturbed and disaggregated nature of the detrital framework. If the clay matrix content observed within this thin section sample is truly representative of the <u>in situ</u> conglomerate interval, macro porosity values can be expected to be comparable to the sample from depth 204.2 feet. Permeability values, however, are likely to be significantly lower (relative to 204.2') due to the very poor sorting of the sedimentary framework.

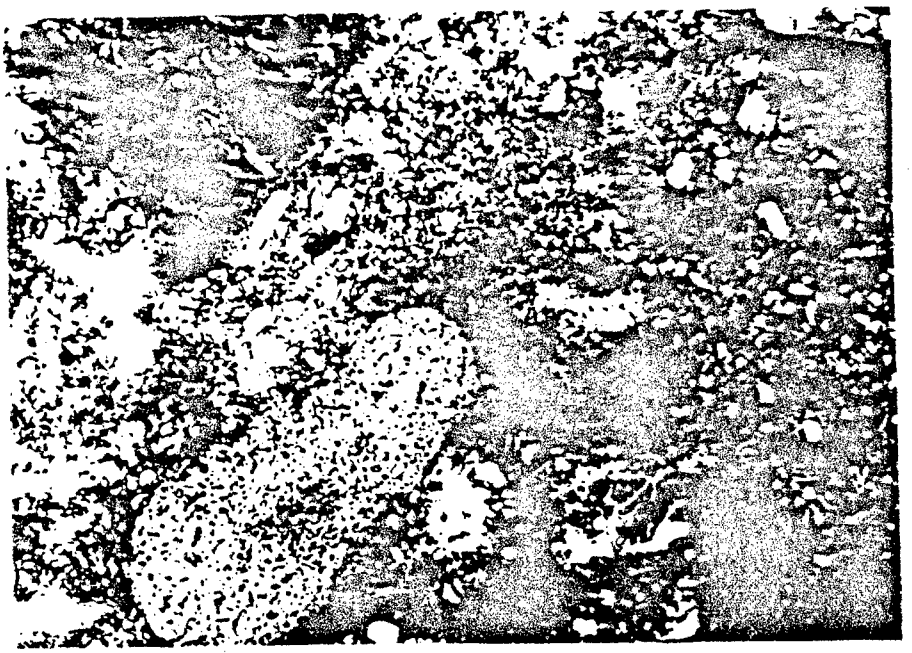
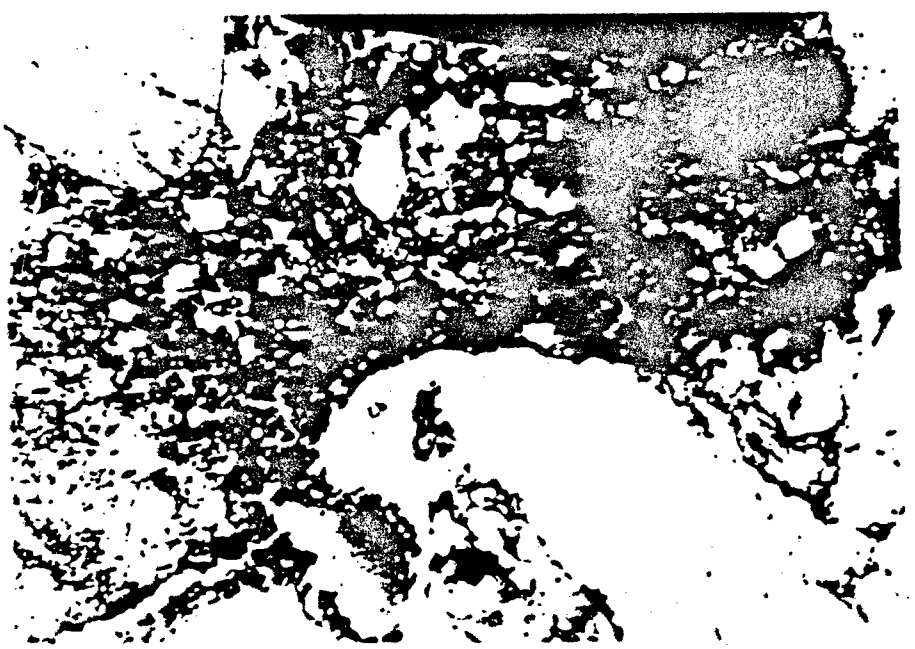
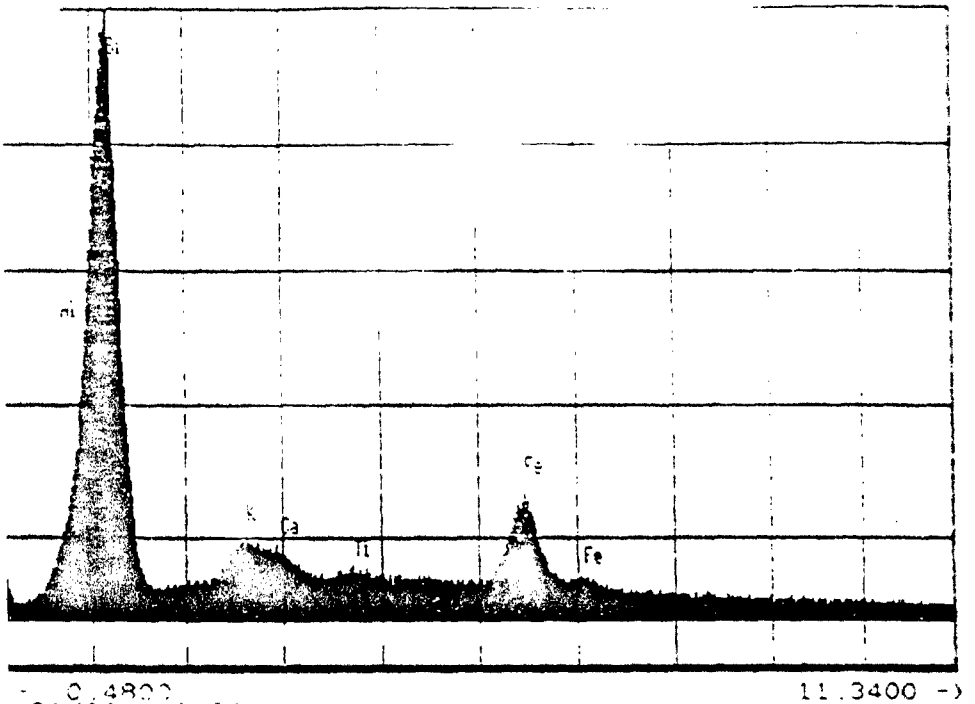


Figure 8. This low magnification photomicrograph provides a general view of the very poorly-sorted character of this sandy pebble conglomerate. The pebble in the right-central portion of this field of view is a sandstone rock fragment, whereas the two pebble-sized grains along the left-hand margin of the photo are volcanic rock fragments. Note the abundance of sand and silt-rich pore-filling clay matrix separating the pebble-sized grains. 15X 1.2"=2.0mm uncrossed nicols

CH2M HILL; Project SAC28722.55.10; McClellan AFB-Davis
235-236 feet

Figure 9. Sand and silt-rich, pore-filling clay matrix minerals (center) flanking pebble-sized rock fragments. The grain in the bottom half of the photomicrograph is a metamorphic rock fragment, whereas the dark-colored grain along the top margin of the photo is a volcanic rock fragment. 32X 2.5"=2.0mm uncrossed nicols



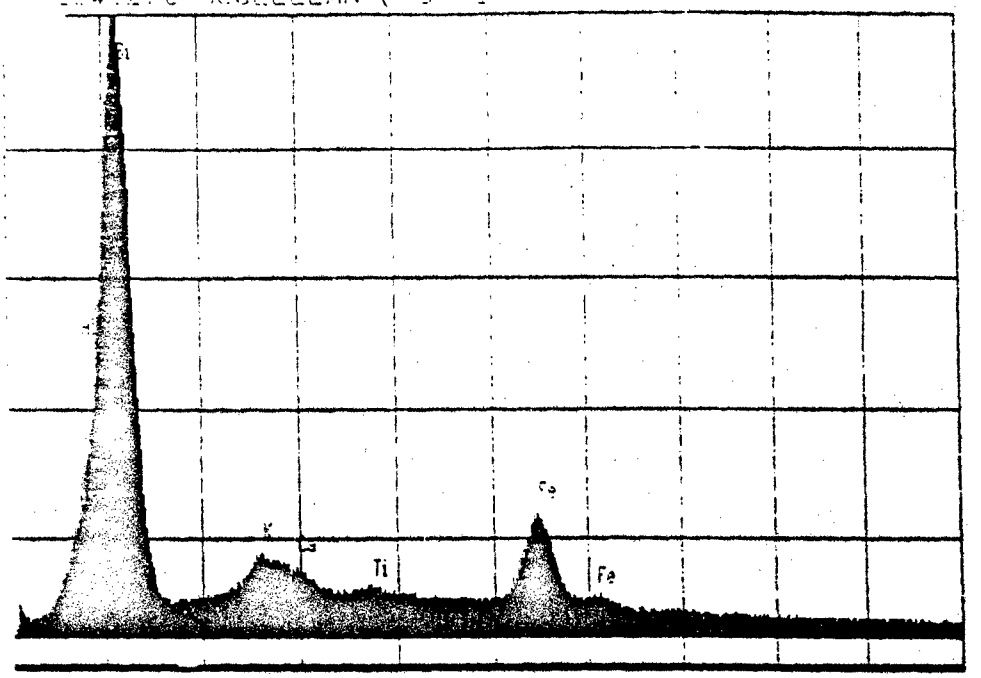


/21/93 3:02 pm

ata From: CH232701 Comments: #1 105 Ft McCLELLAN (93-337)
6/21/93 3:02 pm

Net Area	Normalized Area	Comments
52444.69	86.64	Si
1050.04	1.73	K
2299.02	0.79	Ca
354.22	0.12	Ti
31219.83	10.71	Fe

File: CH232702
#2 204.2ft McCLELLAN (93-327)

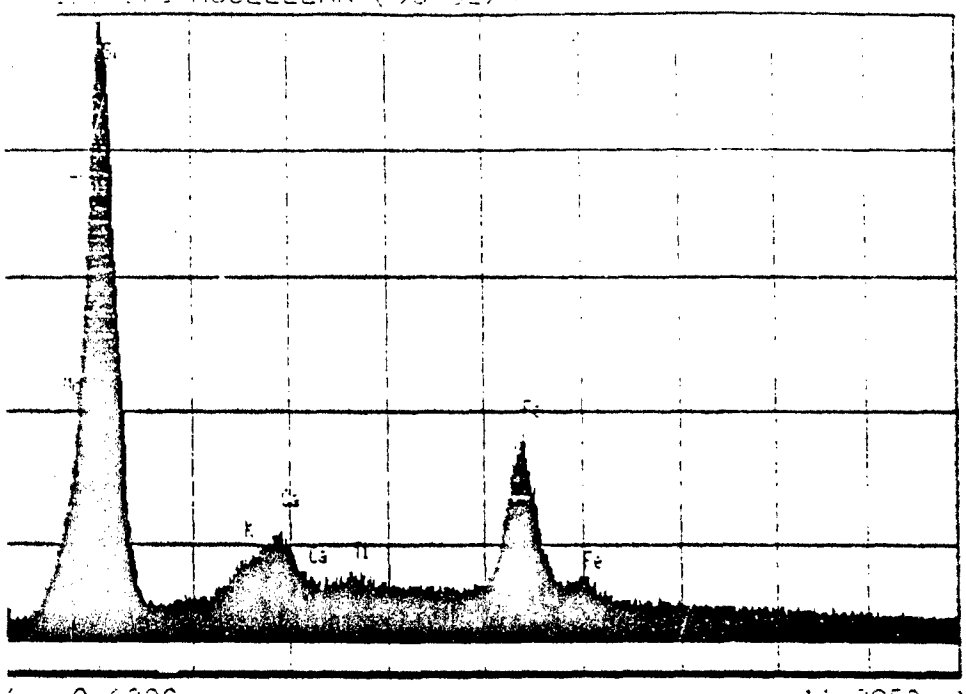


(- 0.4950 11.2950 ->
6/21/93 3:07 pm

Data From: CH232702 Comments: #2 204.2ft McCLELLAN (93-327)
6/21/93 3:07 pm

Net Area	Normalized Area	Comments
320869.51	85.96	Si
7650.03	2.05	K
3897.92	1.04	Ca
1295.07	0.34	Ti
39577.20	10.60	Fe

File: CH232703
#3 235-6ft McCLELLAN (93-327)



0.6000 11.3850 ->
6/21/93 3:13 pm

Data From: CH232703 Comments: #3 235-6ft McCLELLAN (93-327)
@: 6/21/93 3:13 pm

Net Area	Normalized Area	Comments
147575.76	74.26	Si
609.15	0.31	K
12243.04	6.16	Ca
1846.07	0.93	Ti
36462.65	18.35	Fe

GRAIN SIZE DISTRIBUTION ANALYSIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Sample ID: MWE-21 216'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	57.32%
<2.00 >1.00	Very Coarse Sand	22.10%
<1.00 >0.50	Coarse Sand	12.11%
<0.50 >0.25	Medium Sand	6.21%
<0.25 >0.125	Fine Sand	1.48%
<0.125 >0.0625	Very Fine Sand	.62%
<0.0625	Silt and Clay	.16%

Sample ID: MWE-22 200'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	48.87%
<2.00 >1.00	Very Coarse Sand	15.95%
<1.00 >0.50	Coarse Sand	14.37%
<0.50 >0.25	Medium Sand	10.76%
<0.25 >0.125	Fine Sand	8.02%
<0.125 >0.0625	Very Fine Sand	1.74%
<0.0625	Silt and Clay	.29%

Sample ID: MW-19 79'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	30.95%
<2.00 >1.00	Very Coarse Sand	11.61%
<1.00 >0.50	Coarse Sand	21.75%
<0.50 >0.25	Medium Sand	19.91%
<0.25 >0.125	Fine Sand	12.07%
<0.125 >0.0625	Very Fine Sand	2.76%
<0.0625	Silt and Clay	.95%

Sample ID: MWD-20 156'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	67.91%
<2.00 >1.00	Very Coarse Sand	8.06%
<1.00 >0.50	Coarse Sand	8.21%
<0.50 >0.25	Medium Sand	9.54%
<0.25 >0.125	Fine Sand	4.11%
<0.125 >0.0625	Very Fine Sand	1.58%
<0.0625	Silt and Clay	.59%

GRAIN SIZE DISTRIBUTION ANALYSIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Sample ID: MWD-21 160'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	15.52%
<2.00 >1.00	Very Coarse Sand	16.32%
<1.00 >0.50	Coarse Sand	28.09%
<0.50 >0.25	Medium Sand	24.08%
<0.25 >0.125	Fine Sand	10.03%
<0.125 >0.0625	Very Fine Sand	4.64%
<0.0625	Silt and Clay	1.32%

Sample ID: MWD-22 160'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	63.65%
<2.00 >1.00	Very Coarse Sand	8.74%
<1.00 >0.50	Coarse Sand	13.44%
<0.50 >0.25	Medium Sand	11.75%
<0.25 >0.125	Fine Sand	1.79%
<0.125 >0.0625	Very Fine Sand	.52%
<0.0625	Silt and Clay	.11%

Sample ID: MWC-20 105'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	4.83%
<2.00 >1.00	Very Coarse Sand	1.61%
<1.00 >0.50	Coarse Sand	8.94%
<0.50 >0.25	Medium Sand	41.75%
<0.25 >0.125	Fine Sand	31.80%
<0.125 >0.0625	Very Fine Sand	7.21%
<0.0625	Silt and Clay	3.86%

Sample ID: PC-22 93-95'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	12.83%
<2.00 >1.00	Very Coarse Sand	13.02%
<1.00 >0.50	Coarse Sand	33.02%
<0.50 >0.25	Medium Sand	31.68%
<0.25 >0.125	Fine Sand	5.89%
<0.125 >0.0625	Very Fine Sand	2.14%
<0.0625	Silt and Clay	1.42%

GRAIN SIZE DISTRIBUTION ANALSYIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Sample ID: PC-21 91'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	39.86%
<2.00 >1.00	Very Coarse Sand	27.40%
<1.00 >0.50	Coarse Sand	17.22%
<0.50 >0.25	Medium Sand	9.13%
<0.25 >0.125	Fine Sand	3.43%
<0.125 >0.0625	Very Fine Sand	1.96%
<0.0625	Silt and Clay	1.00%

Sample ID: EW3C 100-104'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	48.30%
<2.00 >1.00	Very Coarse Sand	17.19%
<1.00 >0.50	Coarse Sand	9.16%
<0.50 >0.25	Medium Sand	7.32%
<0.25 >0.125	Fine Sand	8.07%
<0.125 >0.0625	Very Fine Sand	5.29%
<0.0625	Silt and Clay	4.67%

Sample ID: EW2C 105-107'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	68.11%
<2.00 >1.00	Very Coarse Sand	14.05%
<1.00 >0.50	Coarse Sand	8.78%
<0.50 >0.25	Medium Sand	6.21%
<0.25 >0.125	Fine Sand	1.72%
<0.125 >0.0625	Very Fine Sand	.99%
<0.0625	Silt and Clay	.14%

Sample ID: EW1C 136'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule/Pebble	53.01%
<2.00 >1.00	Very Coarse Sand	21.43%
<1.00 >0.50	Coarse Sand	16.50%
<0.50 >0.25	Medium Sand	6.16%
<0.25 >0.125	Fine Sand	1.27%
<0.125 >0.0625	Very Fine Sand	.93%
<0.0625	Silt and Clay	.70%

GRAIN SIZE DISTRIBUTION ANALSYIS

CH2M HILL
Project SAC28722.55.10; McClellan AFB-Davis Comm. Site

Sample ID: EW1B 84'

Sieve Size (mm)	Description	Weight Percent
>2.00	Granule	1.58%
<2.00 >1.00	Very Coarse Sand	.55%
<1.00 >0.50	Coarse Sand	.63%
<0.50 >0.25	Medium Sand	3.73%
<0.25 >0.125	Fine Sand	20.72%
<0.125 >0.0625	Very Fine Sand	38.66%
<0.0625	Silt and Clay	34.13%

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Gerald Vogt

DATE: September 9, 1993

SUBJECT: Groundwater Contour Maps
Davis Global Communications Site
Delivery Order 5055

PROJECT: SAC28722.55.19

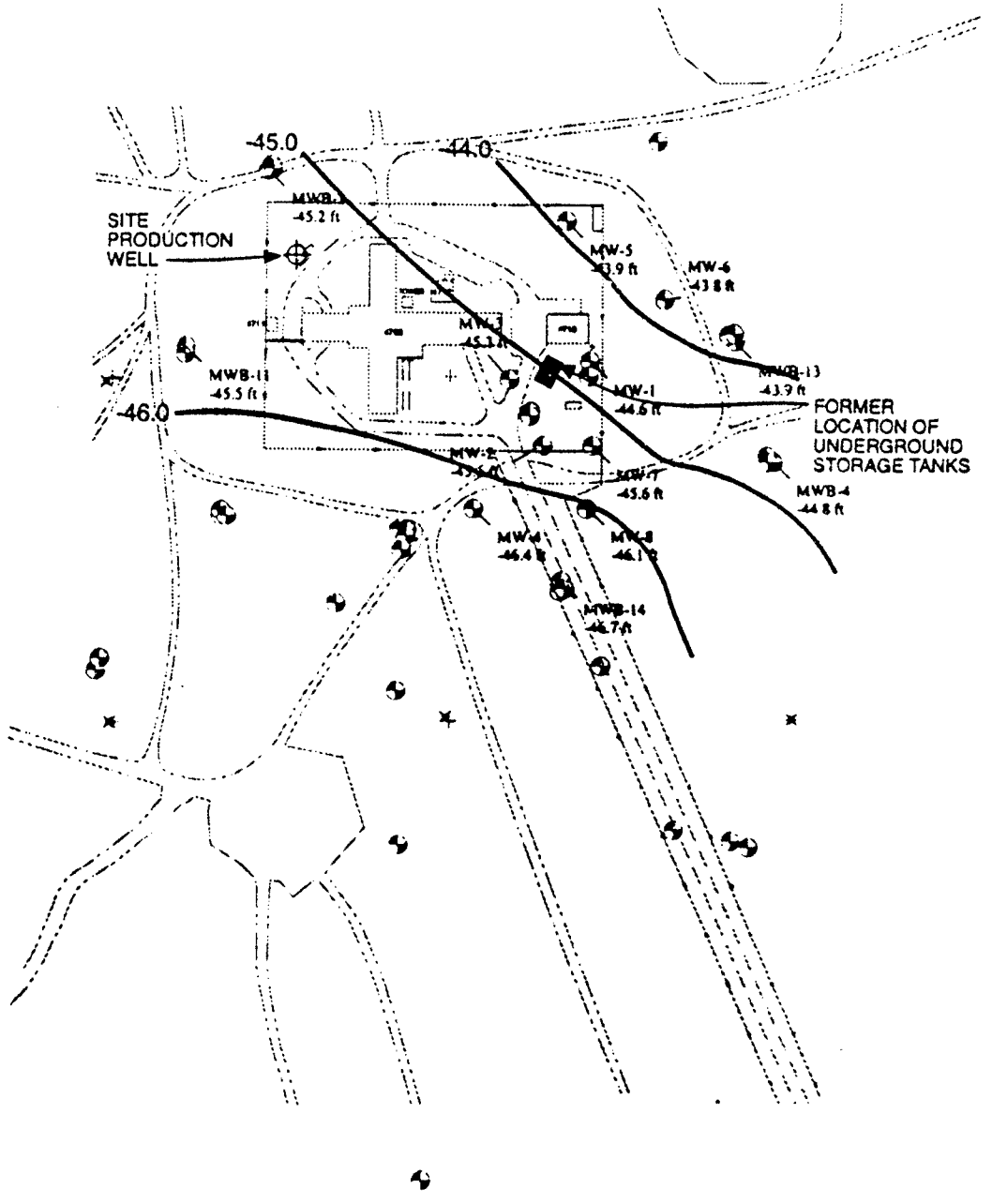
Purpose and Scope

Figures E-1 through E-15 present groundwater contour maps for August 1992, November 1992, March 1993, May 1993, and July 1993 for the B, C, and D aquifers. The groundwater elevations for each well are posted beside the well for each time period. The August 1992 data represent a period of historic low water levels because of California's extended drought and additional groundwater pumping in the vicinity of the Davis Global Communications Site for the California Water Banking Project. The levels presented for March 1993 represent a period of high groundwater levels because of greater than normal rainfall.

The water level contours for the B and C aquifers are nearly identical while the D aquifer levels are typically flat across the site. Flow directions range from south to northwest in the B and C aquifers. Summer flow directions are usually to the southwest in these two aquifers.

Further interpretation of these contour maps is presented in Chapter 3 of the Remedial Investigation/Feasibility Study report, Hydrogeologic Conditions.

Time-concentration plots for Monitoring Wells MW-2, MW-4, MW-6, MW-7, MW-8, MWB-14, MWC-14, MWD-14, MDW-2, and MWE-3 are presented in Attachment E-1. Detected SCOCs from 1988 through February 1993 are plotted on the graphs along with water levels. Further interpretation of these plots is presented in Chapter 4 of the RI/FS Report.



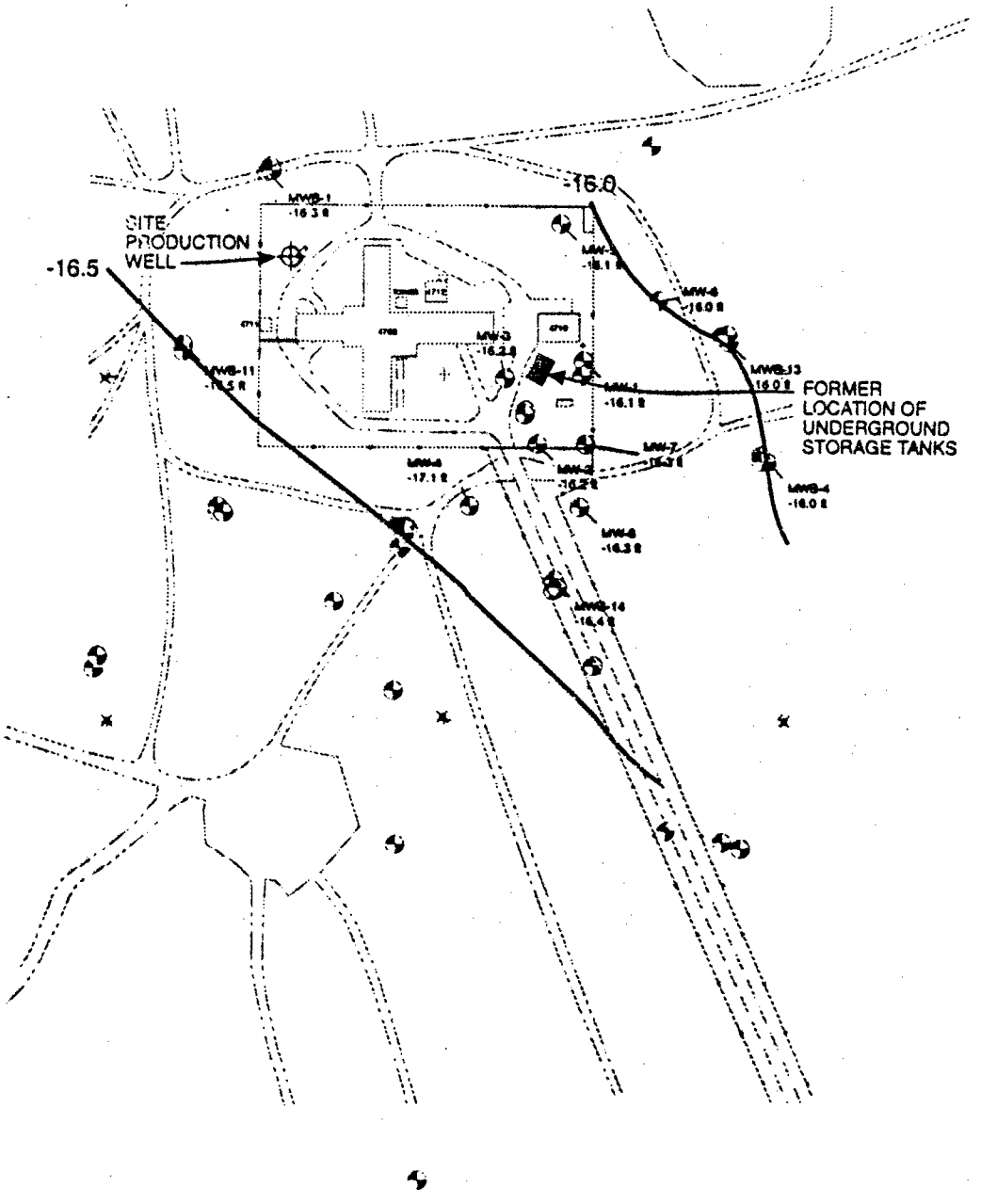
LEGEND

GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-1
WATER LEVEL CONTOURS
B AQUIFER, 8/7/92
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_88



N

SCALE (Approximate)

0 250 FEET

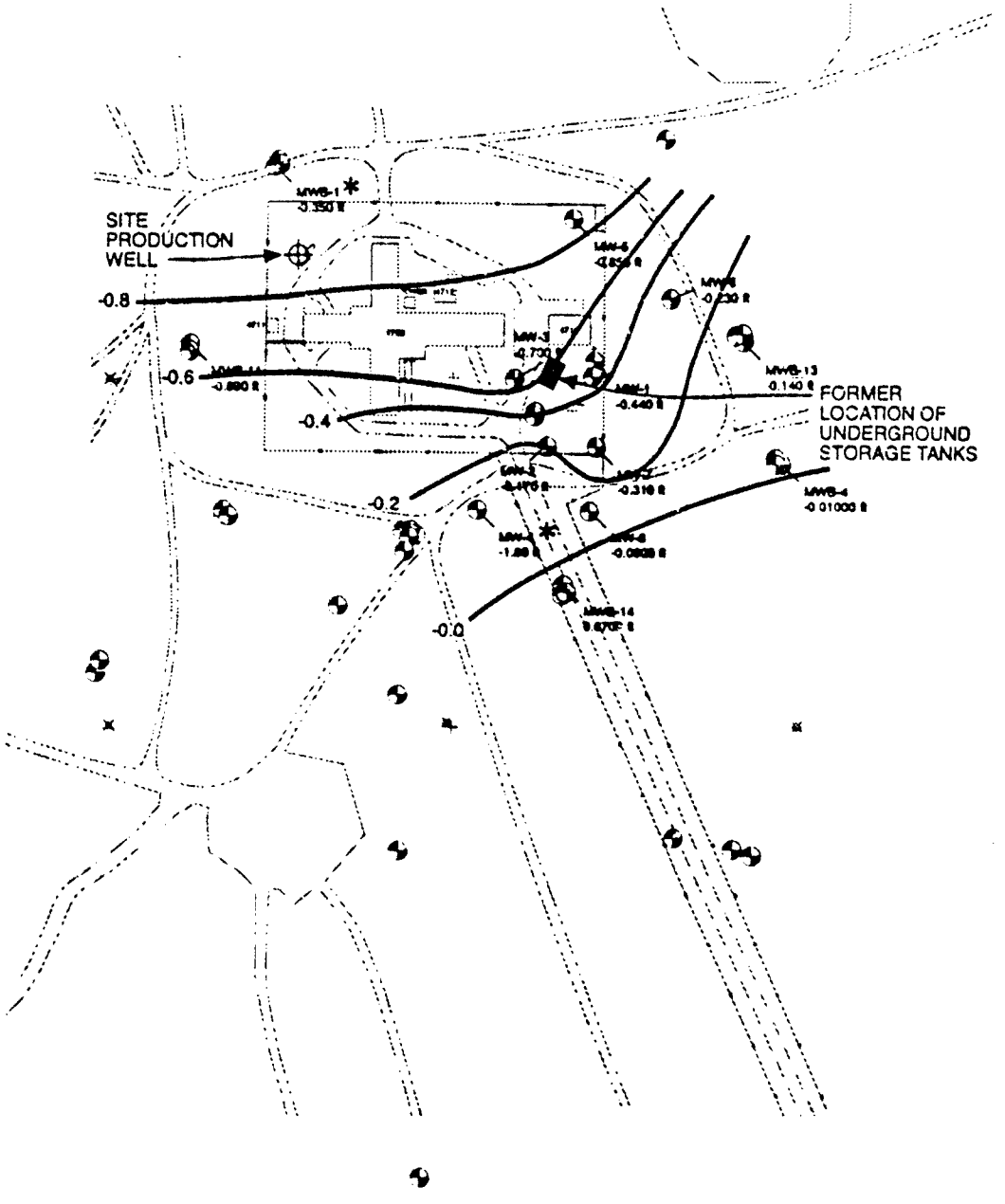
LEGEND

GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-2
WATER LEVEL CONTOURS
B AQUIFER, 11/25/92
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

ROD1412_B1
3058.19

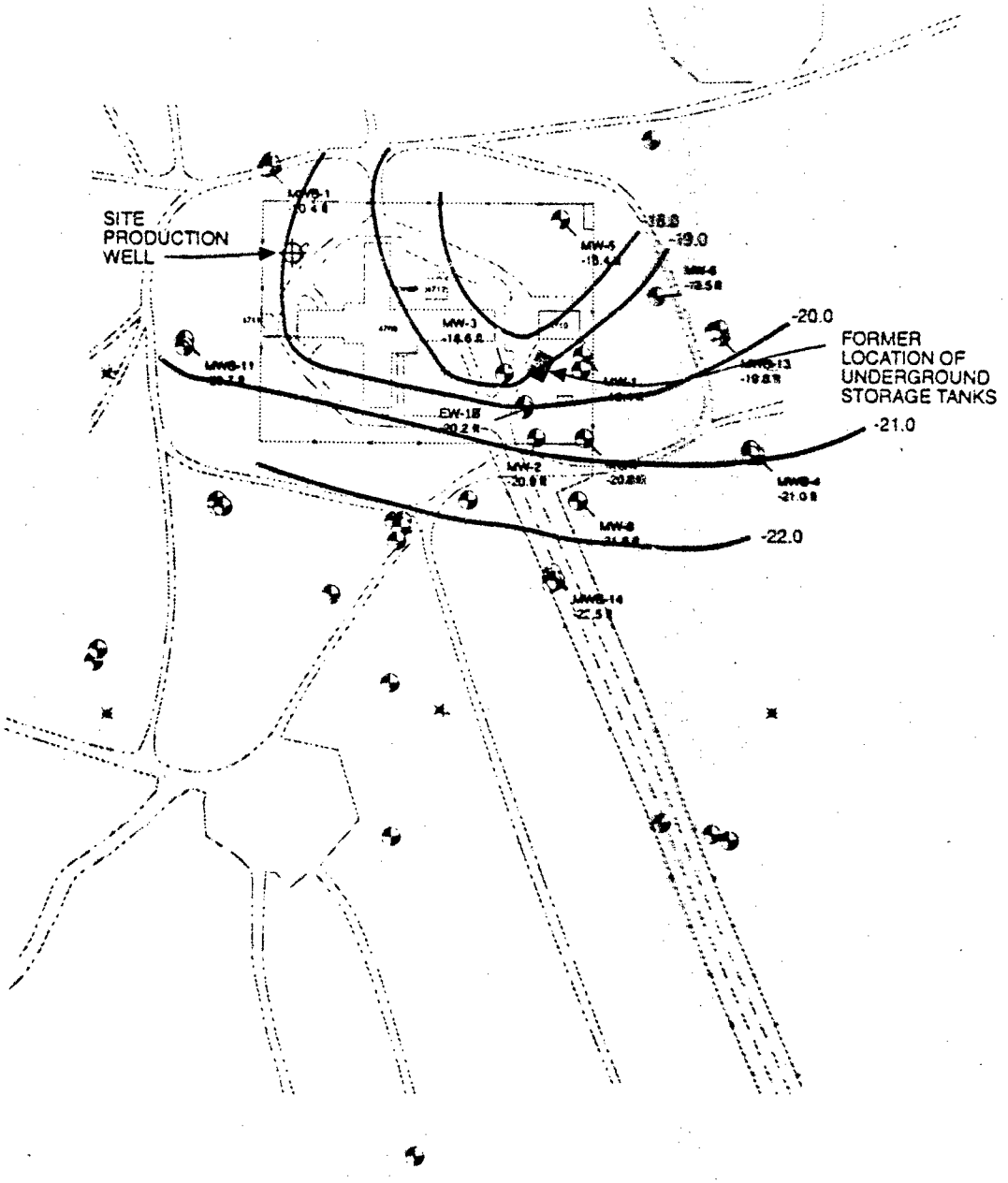


LEGEND

- GROUNDWATER MONITORING WELL
- ★ DATA POINT NOT USED IN CONTOURING

NOTE: Locations based on IRPIMS data

FIGURE E-3
WATER LEVEL CONTOURS
B AQUIFER, 3/31/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA



N

SCALE (Approximate)

0 250 FEET

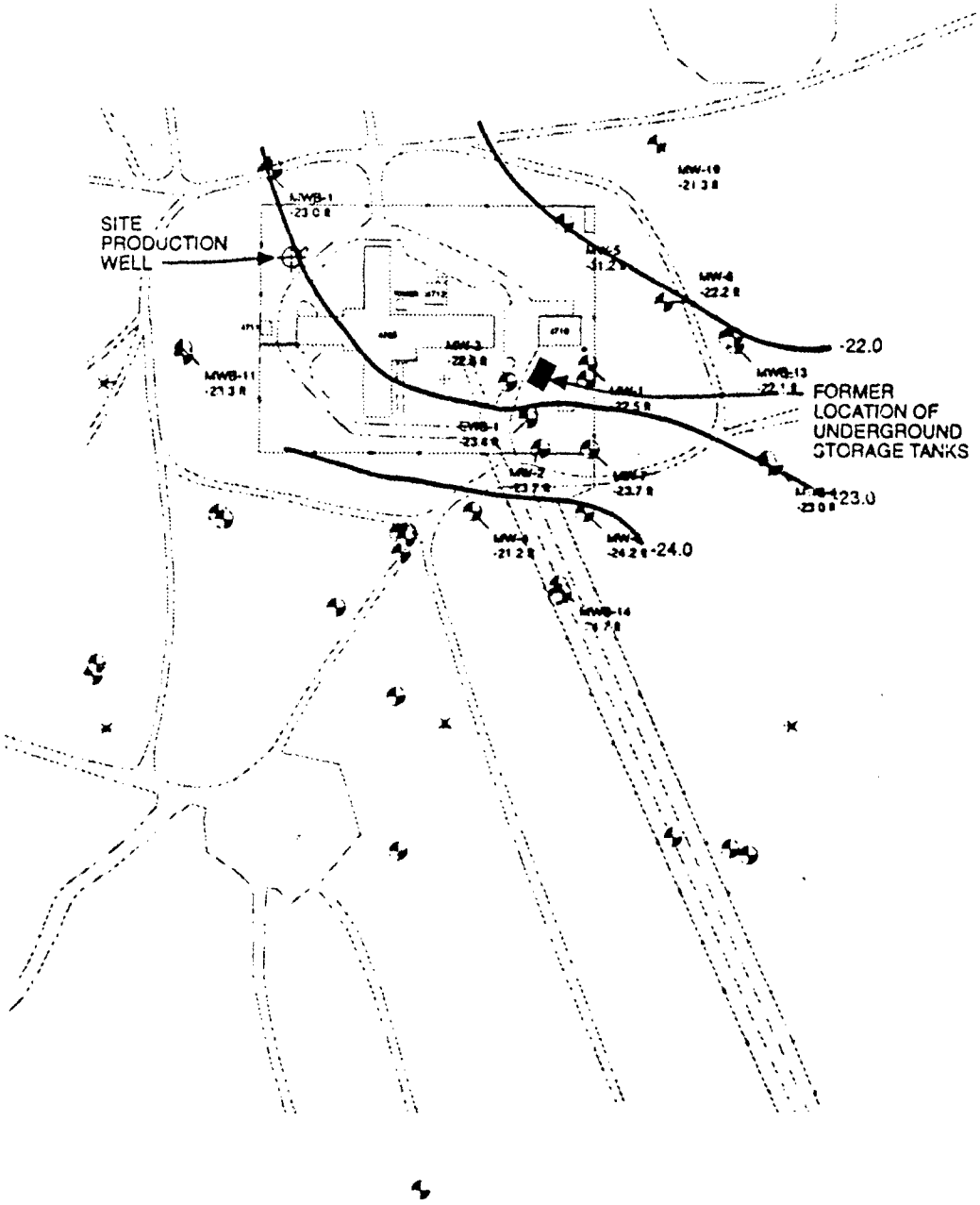
LEGEND

GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-4
WATER LEVEL CONTOURS
B AQUIFER, 5/25/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

ROD1412.dgn
5055.19



N

SCALE (Approximate)

0 250 FEET

LEGEND

GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-5
WATER LEVEL CONTOURS
B AQUIFER, 7/6/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE

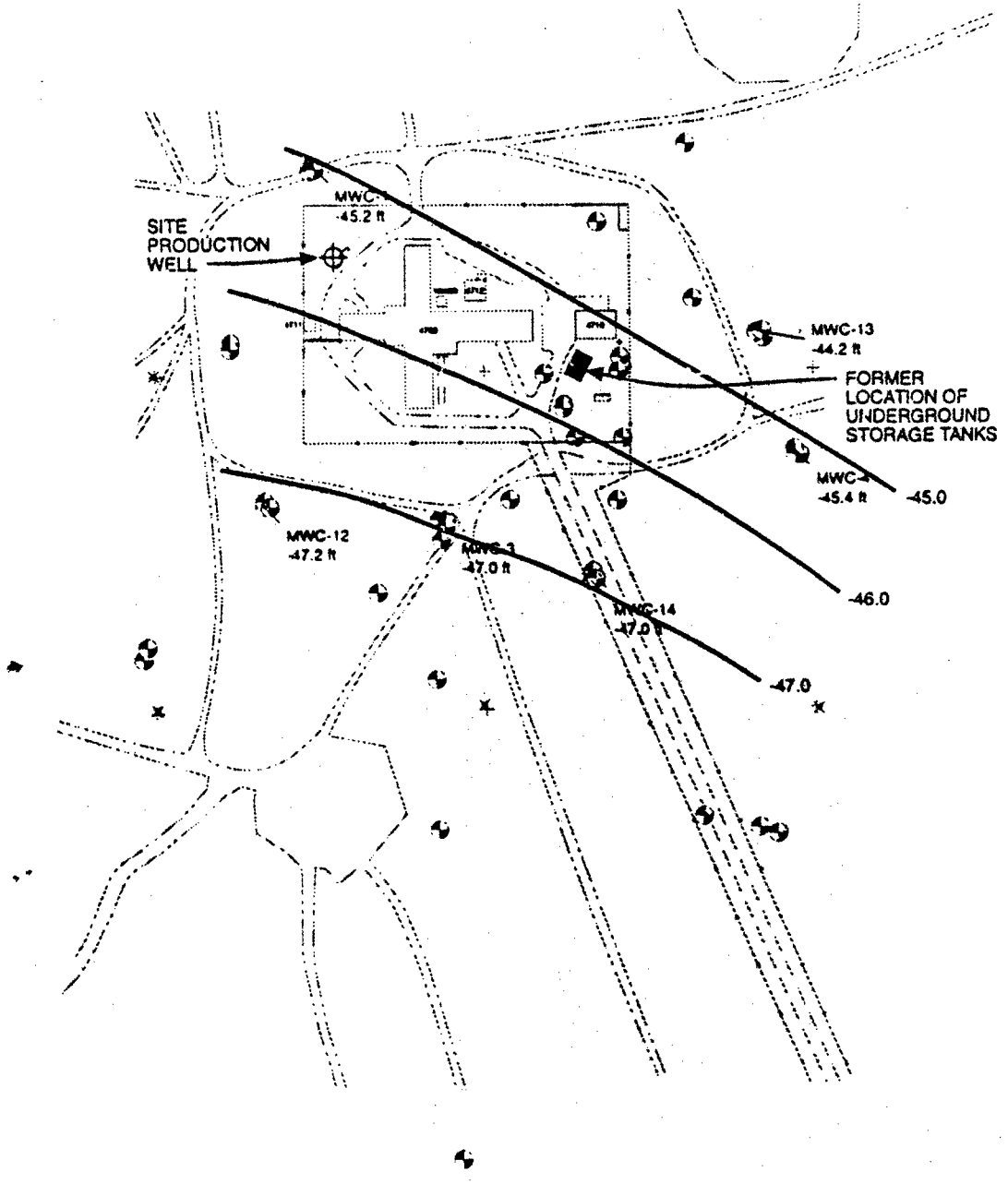
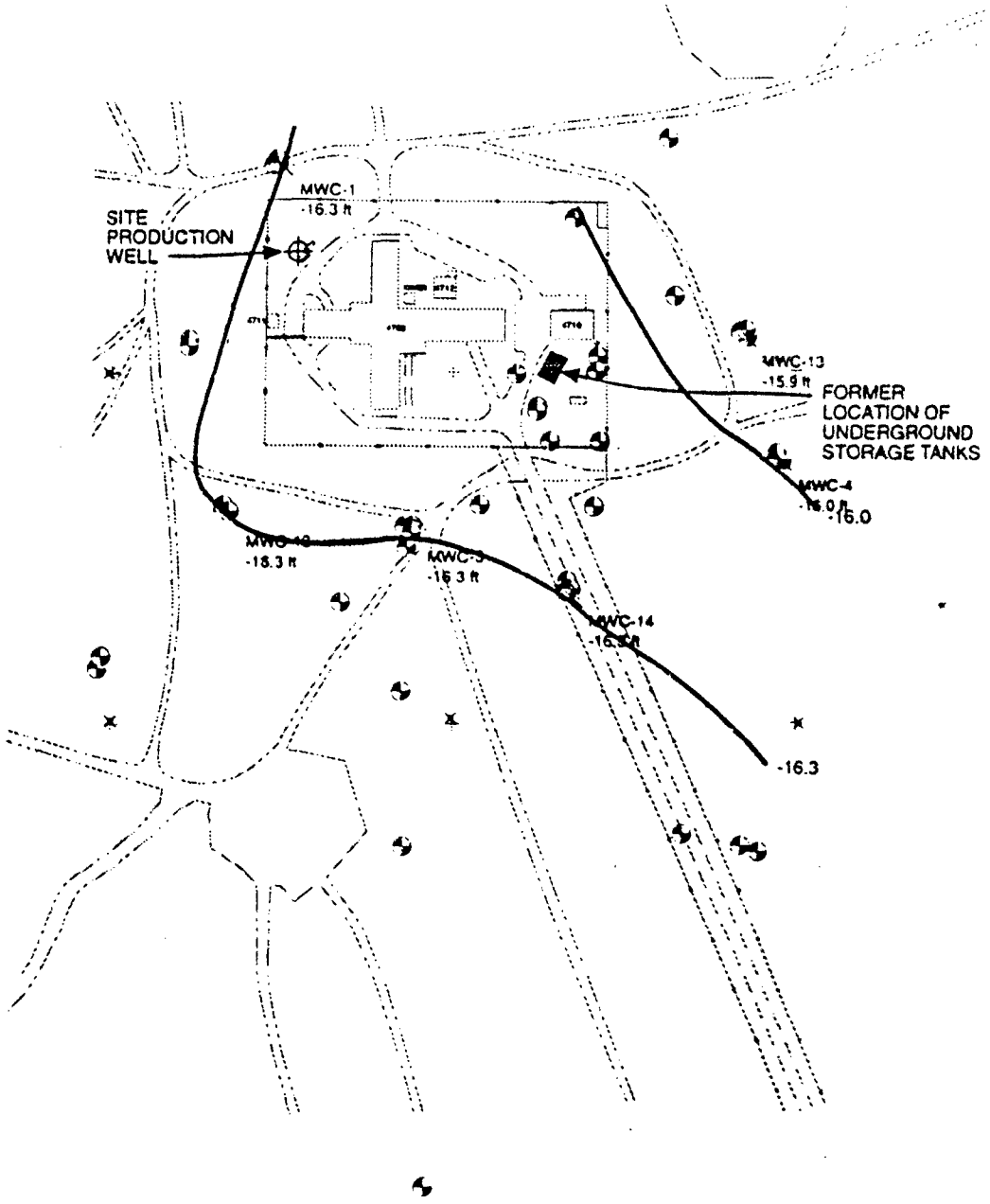


FIGURE E-6
WATER LEVEL CONTOURS
C AQUIFER, 8/7/92
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RD01412_98
5055.19

CH2MHILL



LEGEND

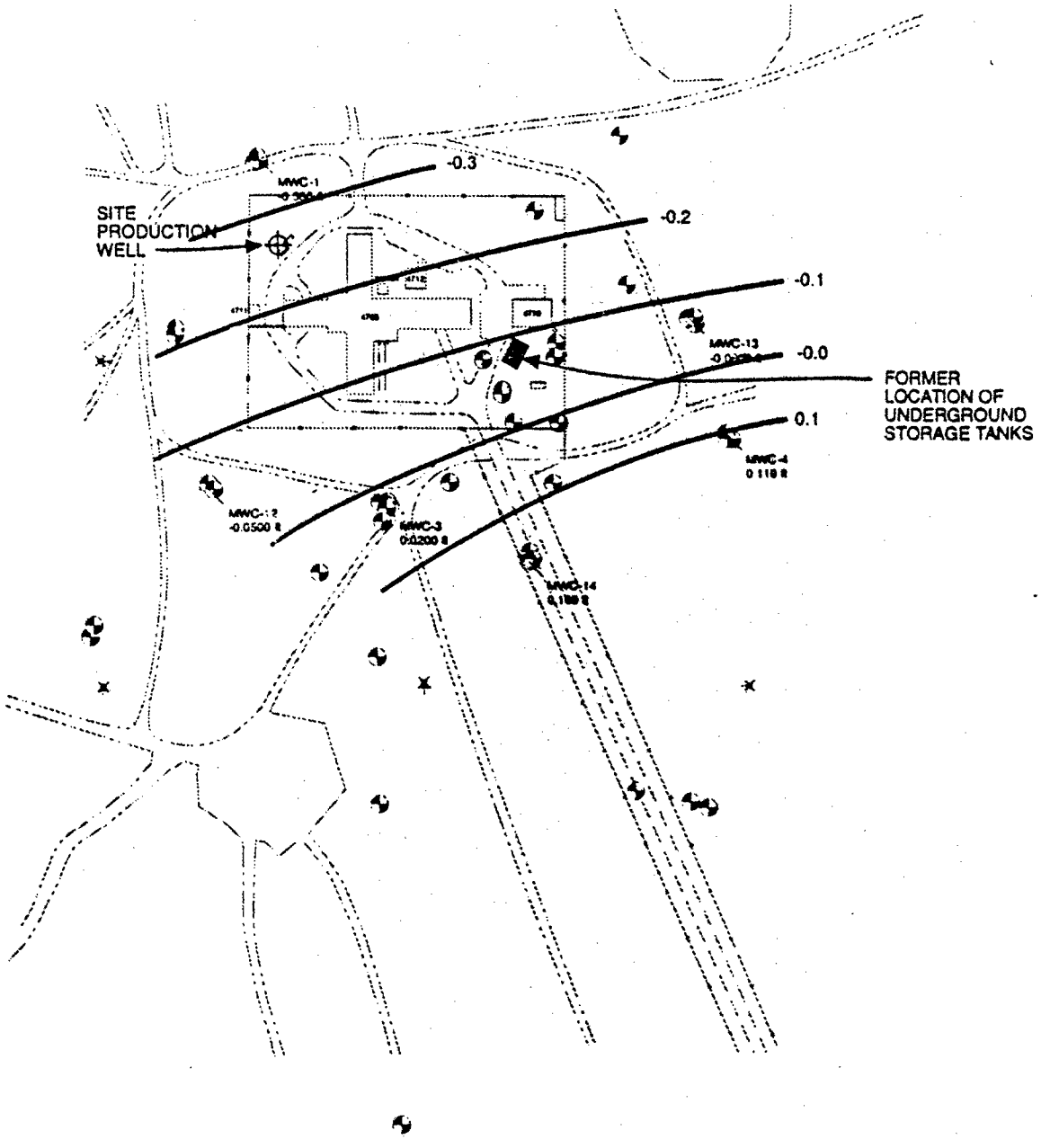
GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-7
WATER LEVEL CONTOURS
C AQUIFER, 11/25/92
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_86
5055.19

CH2MHILL



N

SCALE (Approximate)

0 250 FEET

LEGEND

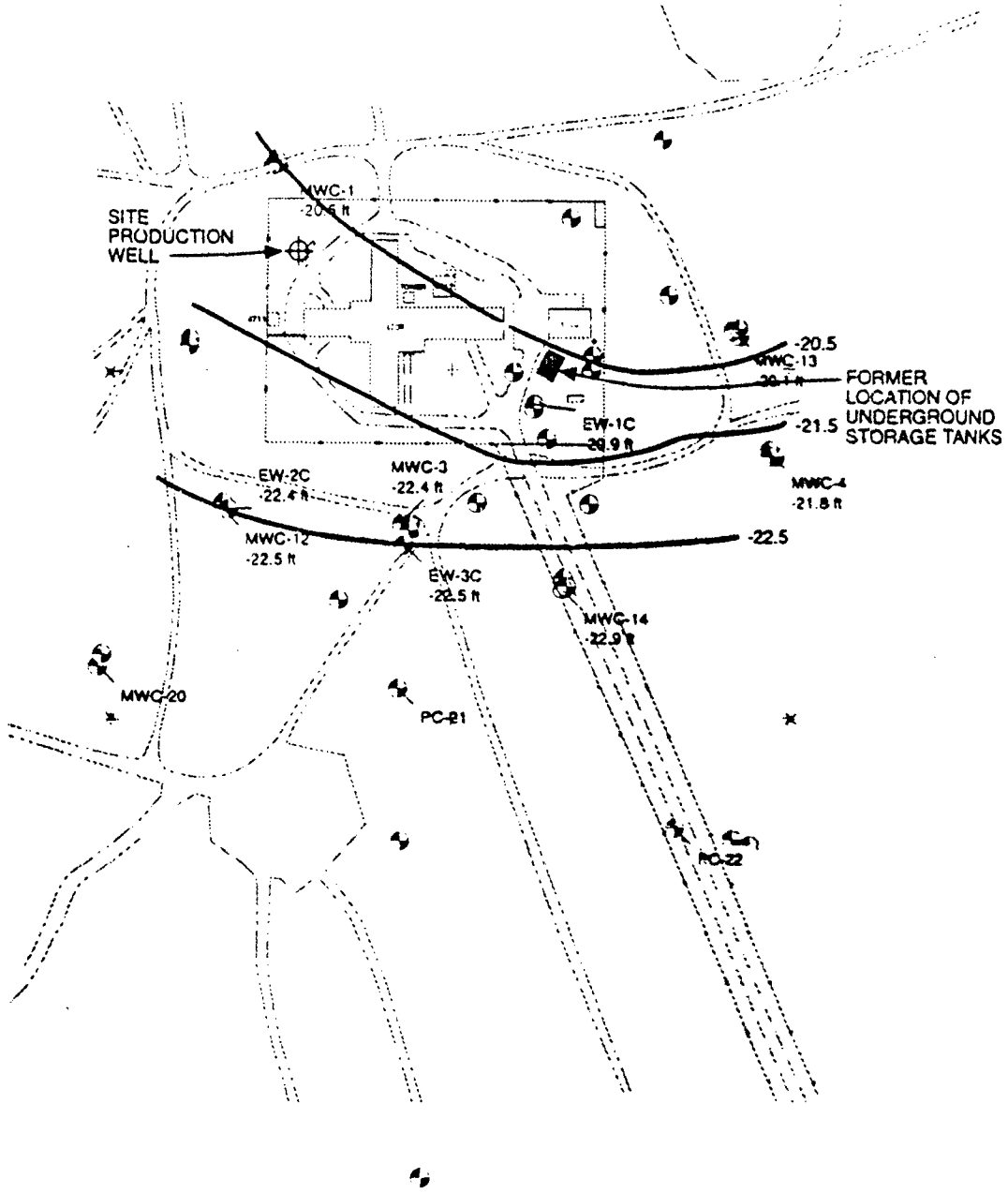
GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E–8
WATER LEVEL CONTOURS
C AQUIFER, 3/31/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_07
5055.19

CH2MHILL



LEGEND

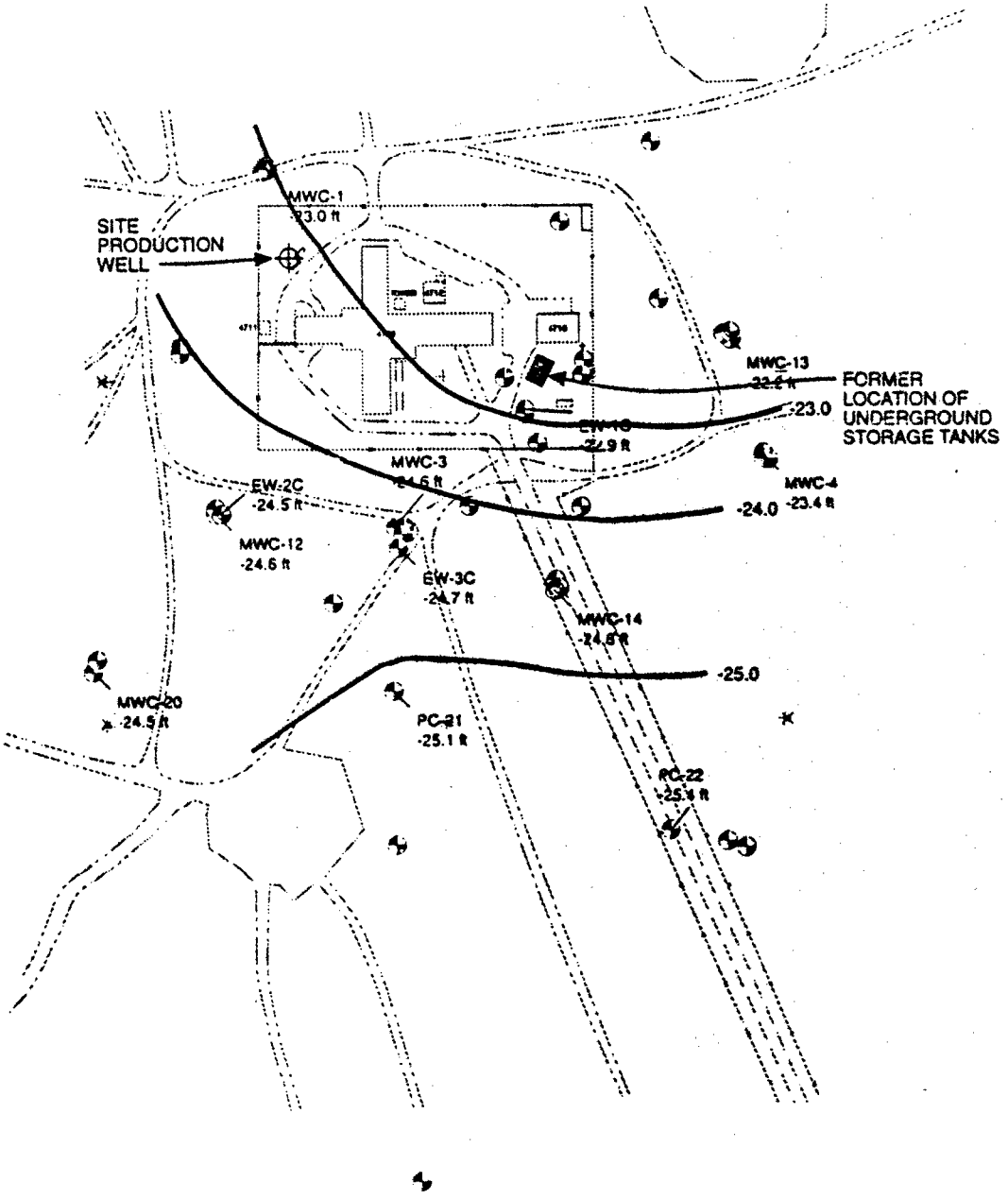
GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-9
WATER LEVEL CONTOURS
C AQUIFER, 5/25/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412_88
5055.19



LEGEND

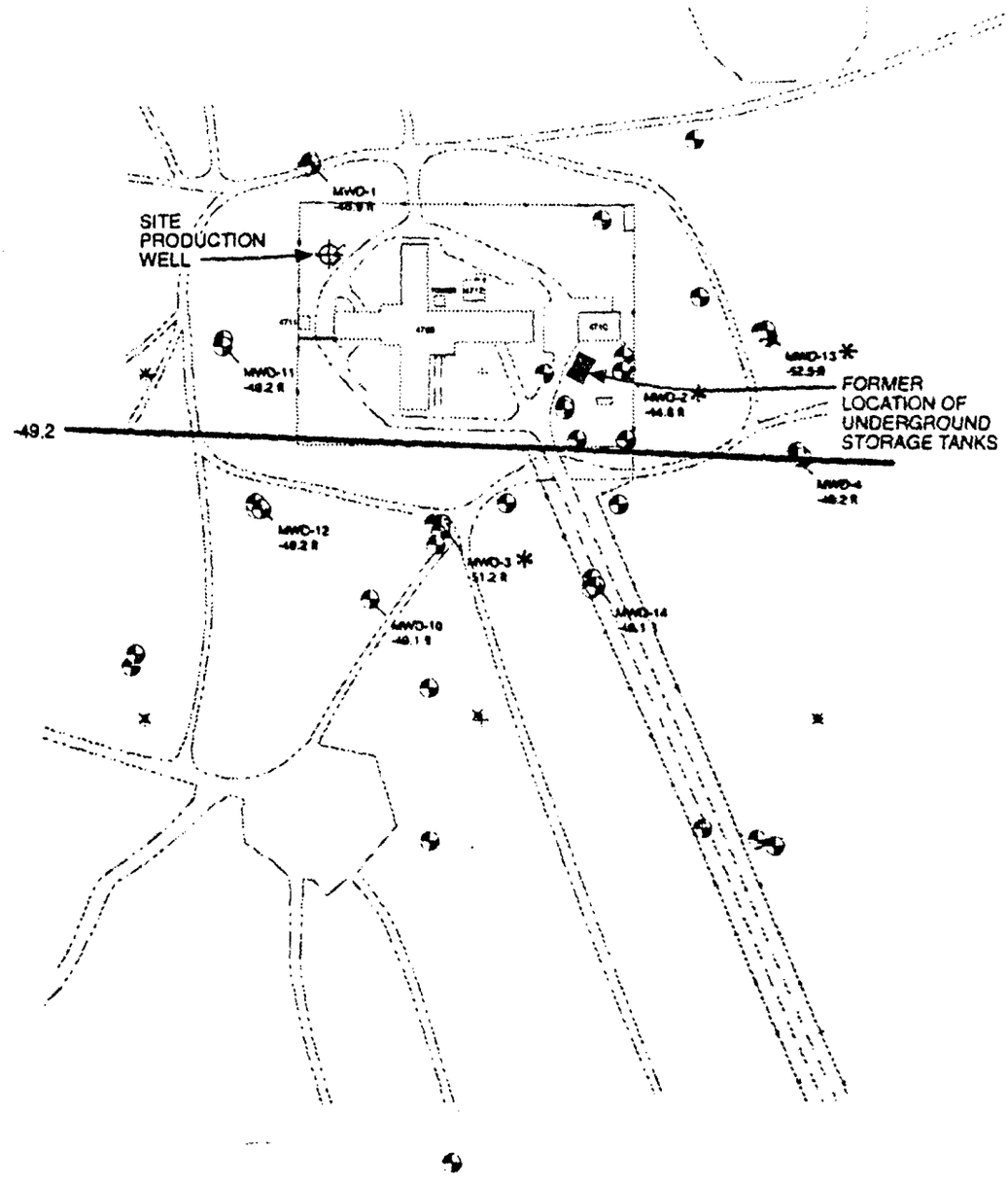
GROUNDWATER MONITORING WELL

NOTE: Locations based on IRPIMS data

FIGURE E-10
WATER LEVEL CONTOURS
C AQUIFER, 7/6/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

ROC1412_e0
5055.10

CH2MHILL



N

SCALE (Approximate)

0 250 FEET

LEGEND

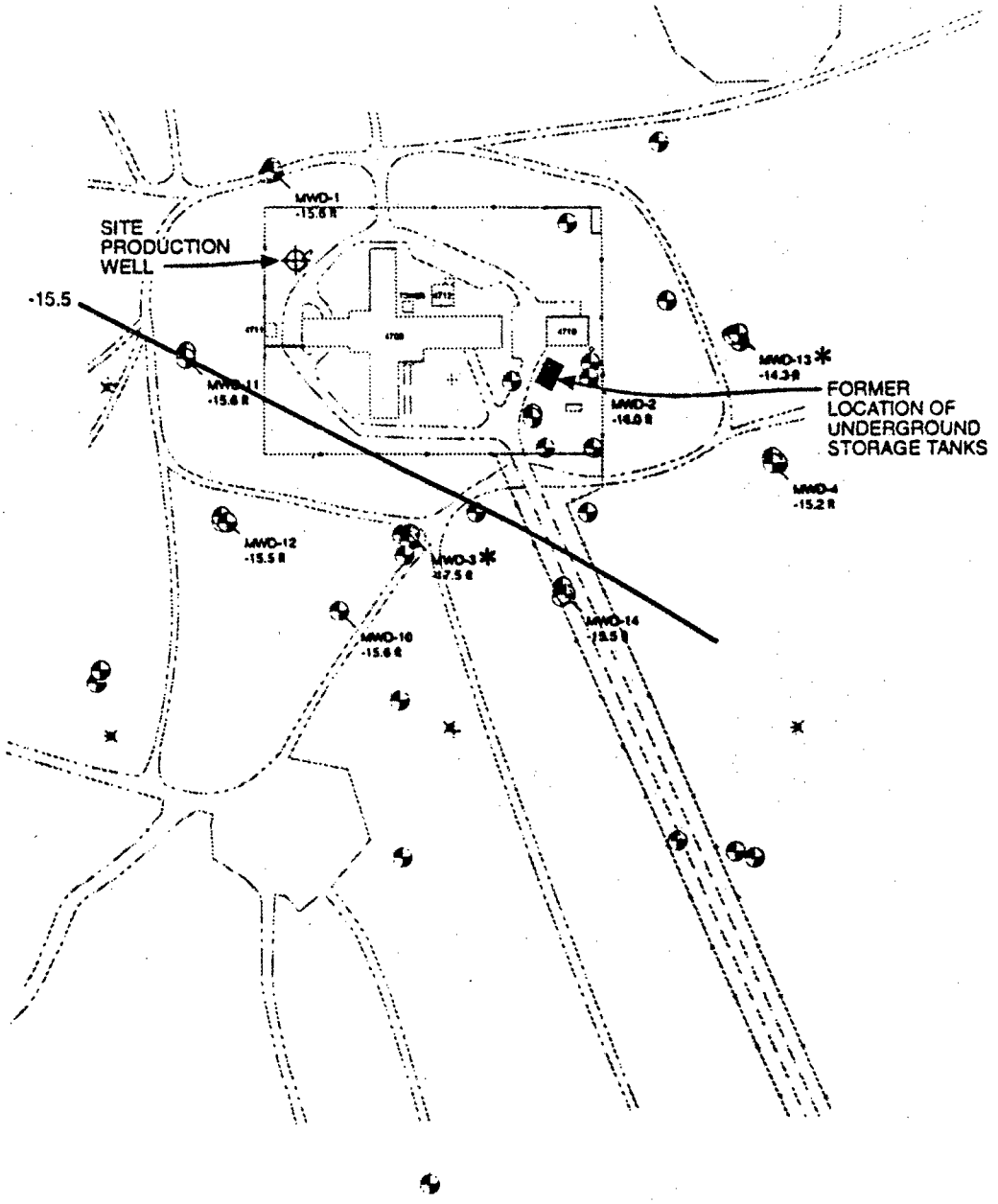
- GROUNDWATER MONITORING WELL
- ✱ DATA POINT NOT USED IN CONTOURING

NOTE: Locations based on IRPIMS data

FIGURE E-11
WATER LEVEL CONTOURS
D AQUIFER, 8/7/92
DMMS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_00
5056.19

CH2MHILL



N

SCALE (Approximate)

0 250 FEET

LEGEND

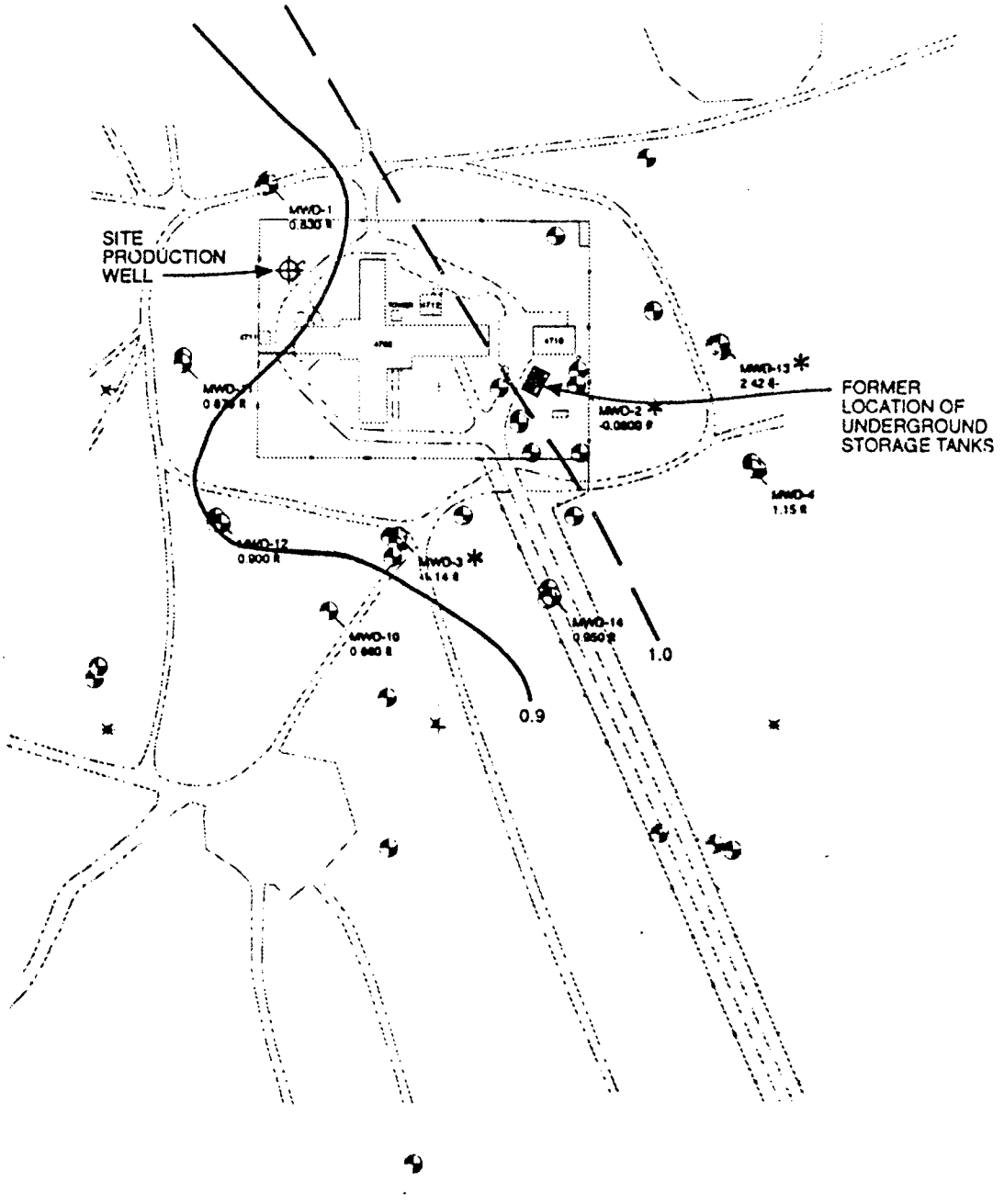
- GROUNDWATER MONITORING WELL
- ★ DATA POINT NOT USED IN CONTOURING

NOTE: Locations based on IRPIMS data

FIGURE E-12
WATER LEVEL CONTOURS
D AQUIFER, 11/25/92
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_91
5055.19

CH2MHILL



N

SCALE (Approximate)

0 250 FEET

LEGEND

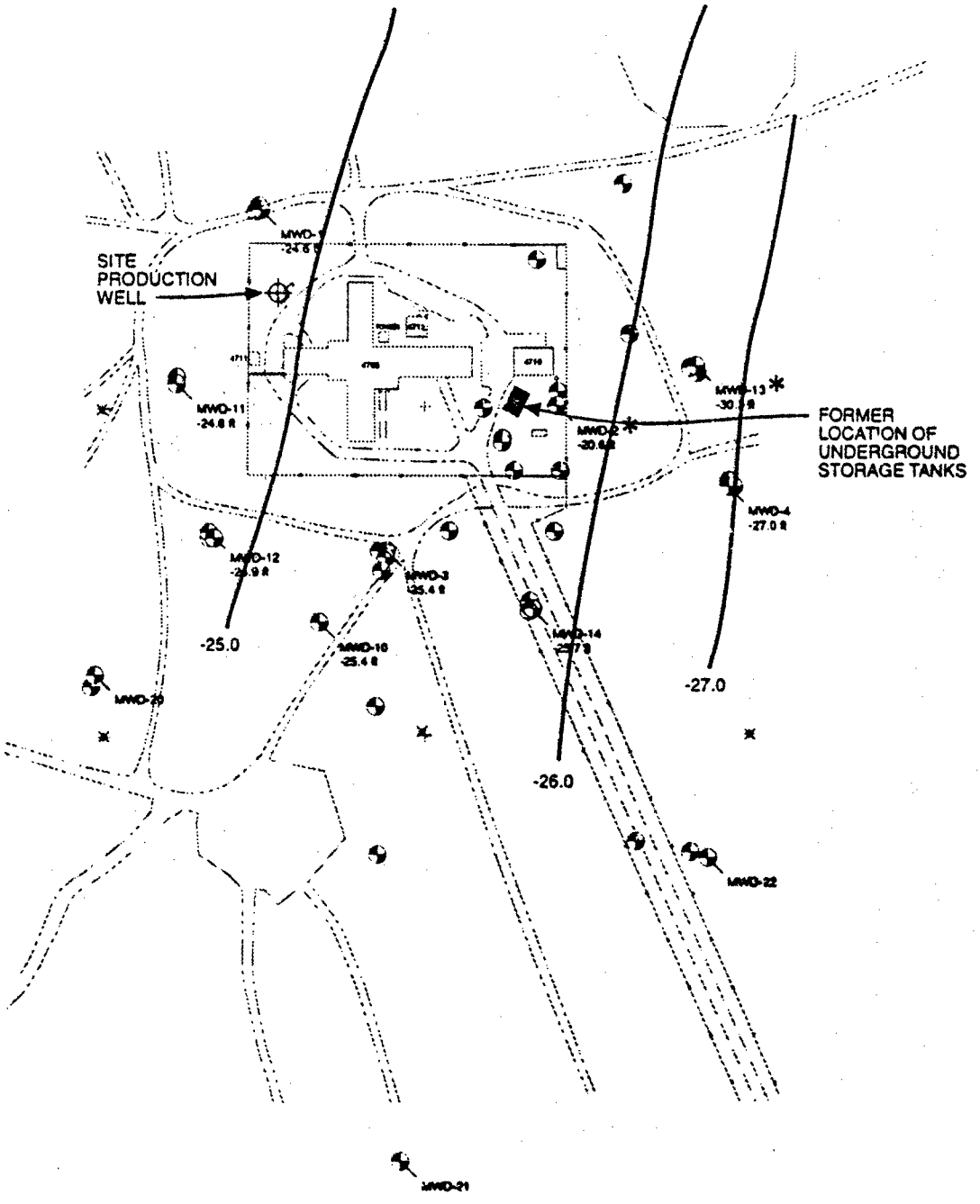
- GROUNDWATER MONITORING WELL
- ★ DATA POINT NOT USED IN CONTOURING

NOTE: Locations based on IRPIMS data

FIGURE E-13
WATER LEVEL CONTOURS
D AQUIFER, 3/31/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CHEMHILL

ROD1412_9R
5055 19



SCALE (Approximate)

0 250 FEET

LEGEND

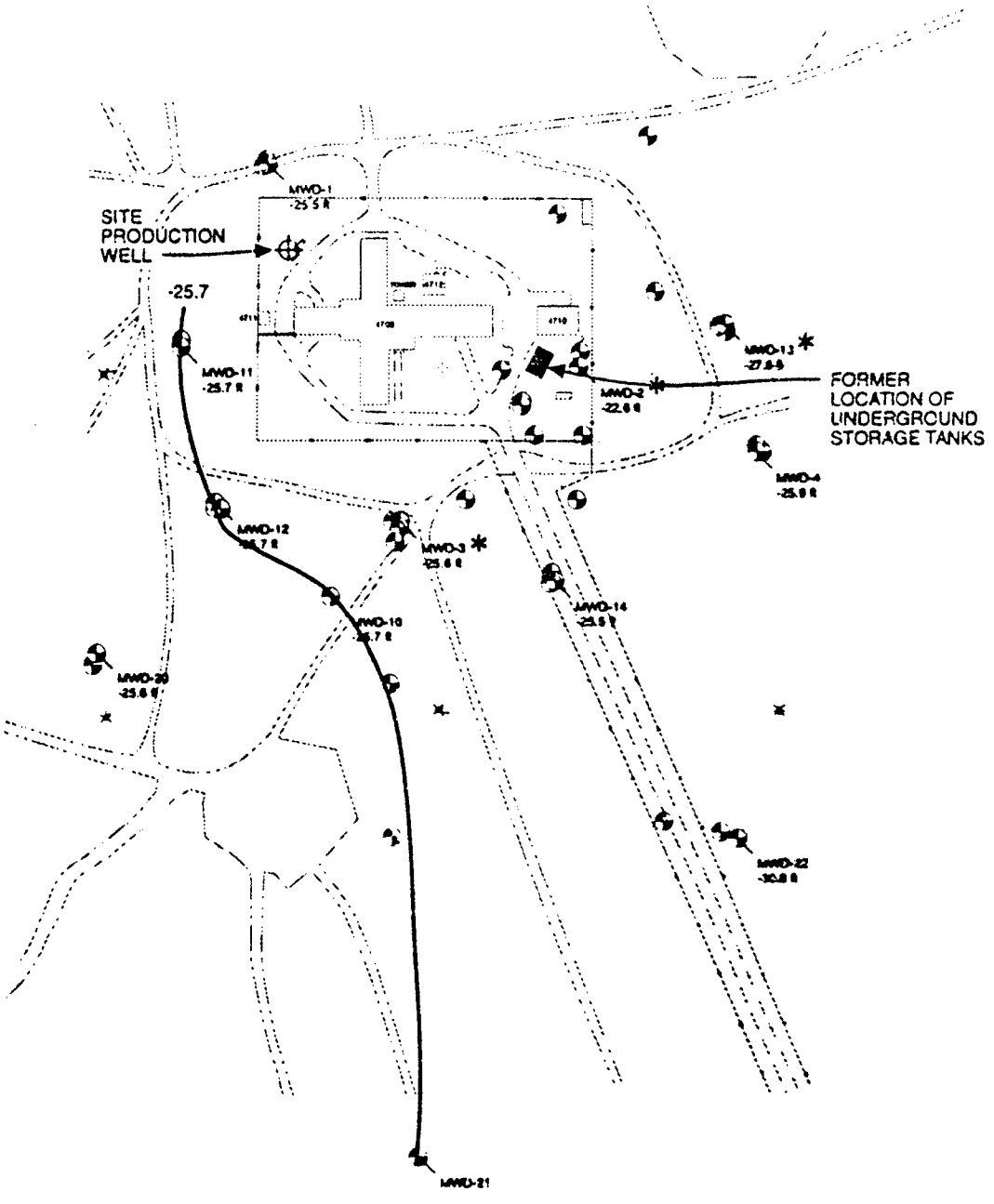
- GROUNDWATER MONITORING WELL
- ★ DATA POINT NOT USED IN CONTOURING

NOTE: Locations based on IRPIMS data

FIGURE E-14
WATER LEVEL CONTOURS
D AQUIFER, 5/25/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

ROD1412_93
5055.19



N

SCALE (Approximate)

0 250 FEET

LEGEND

- GROUNDWATER MONITORING WELL
- ★ DATA POINT NOT USED IN CONTOURING

NOTE: Locations based on IRPIMS data

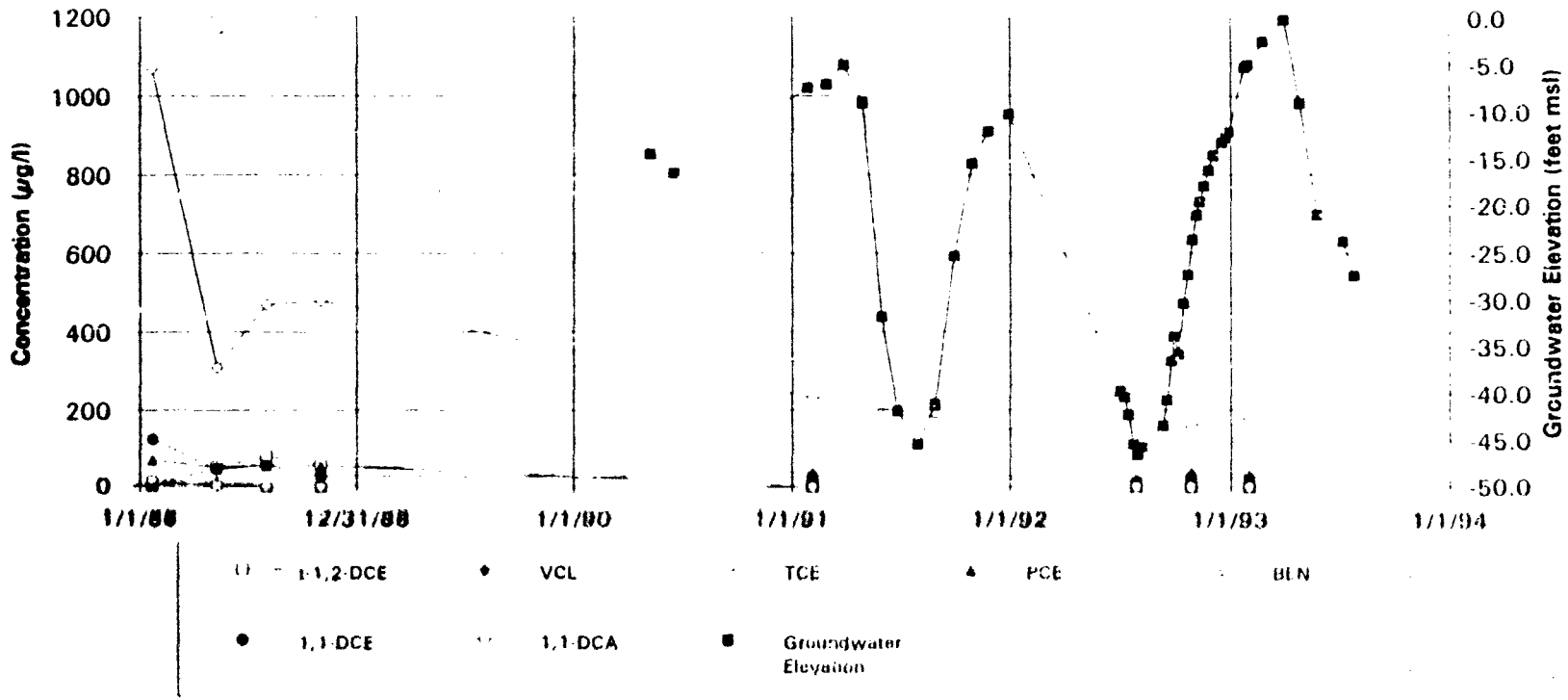
FIGURE E-15
WATER LEVEL CONTOURS
D AQUIFER, 7/6/93
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412_94
5055.19

Attachment E-1

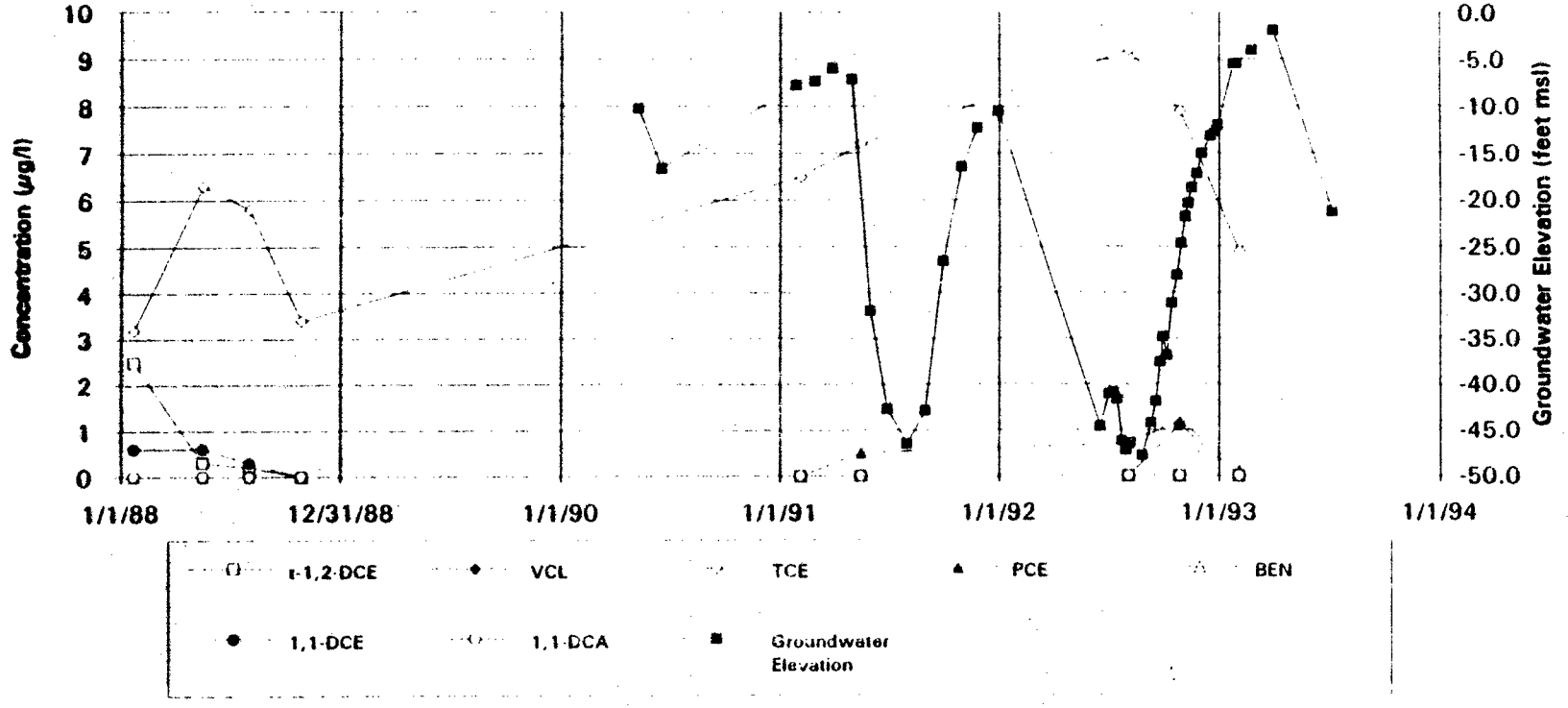
MW-2



G:\users\data\emr\davis\MW 2.XLC

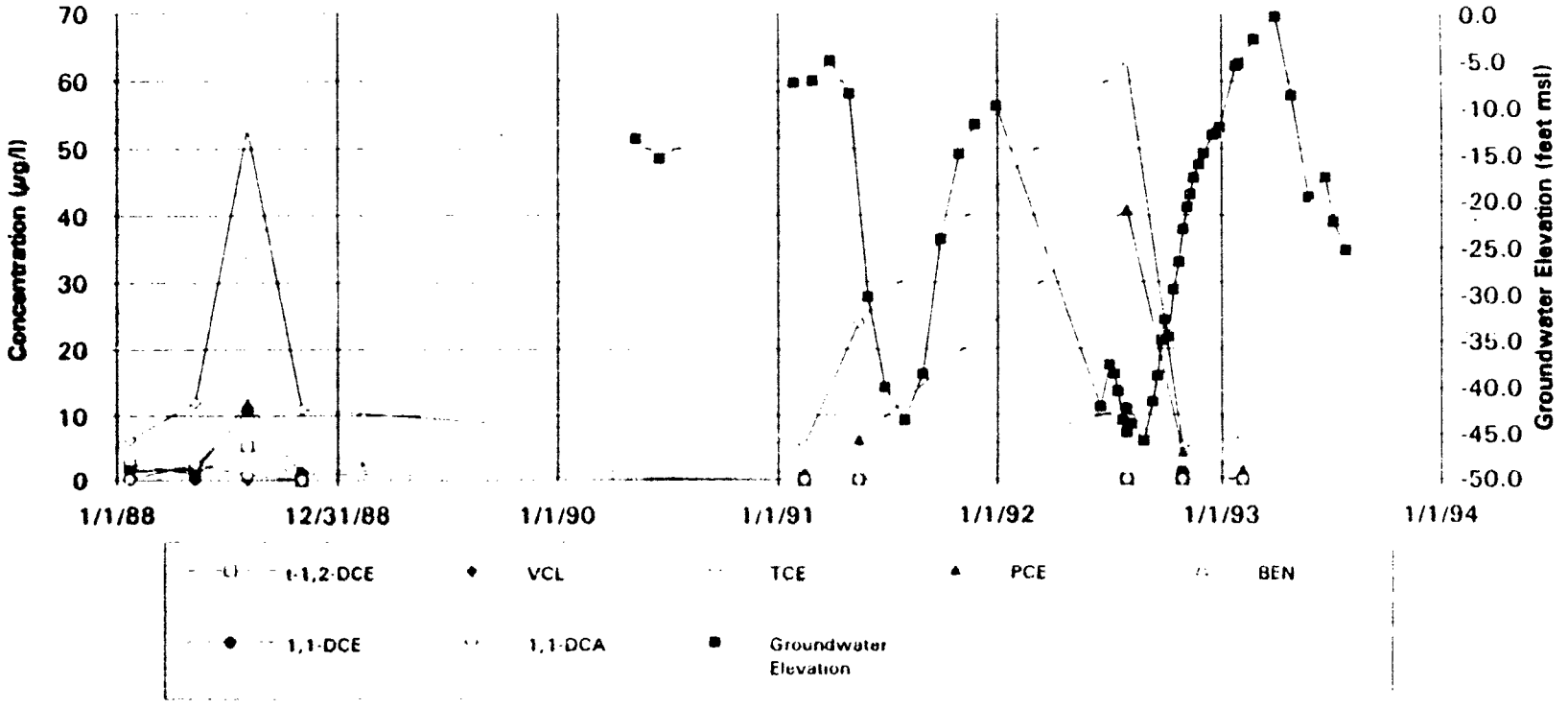
9.7 93

MW-4

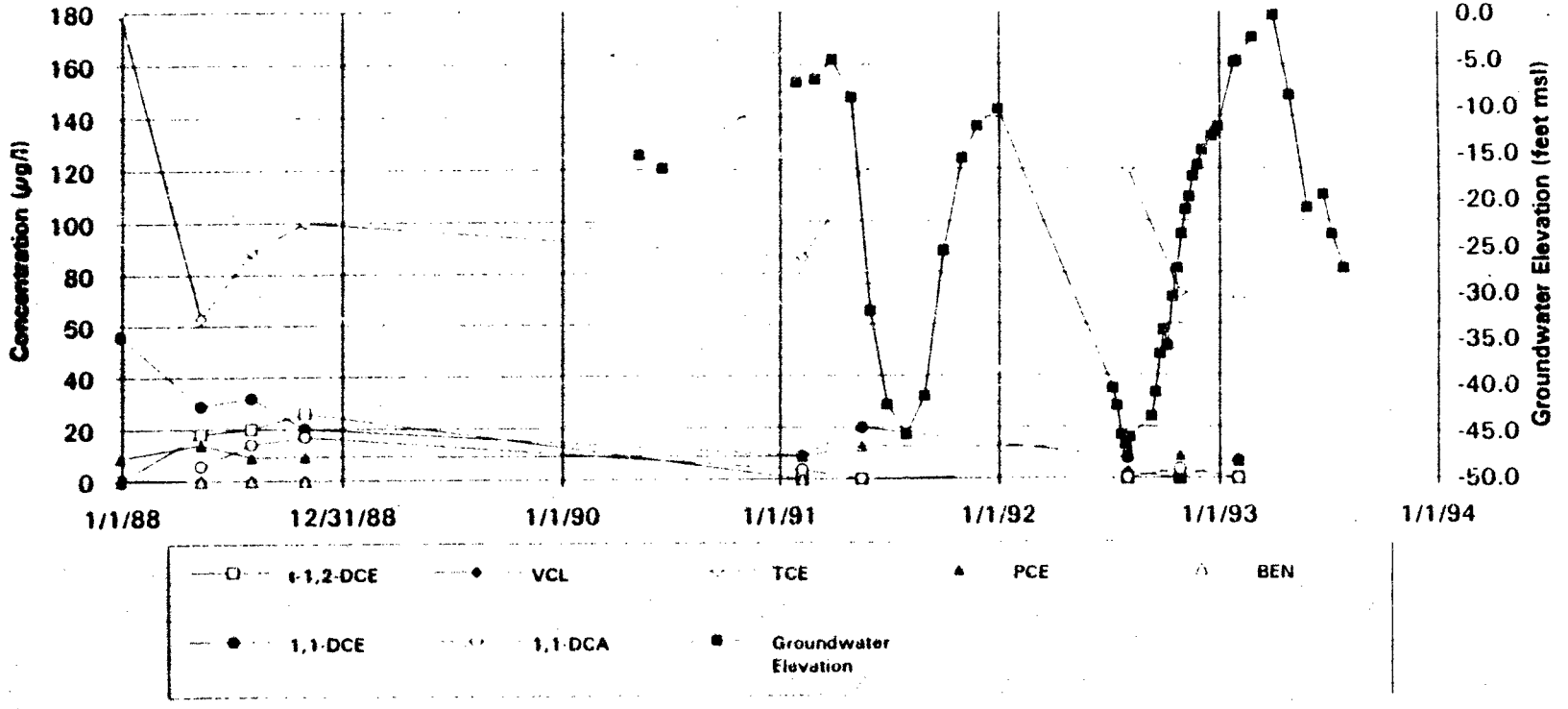


G:\users\da\emr\davis\MW-4.XLC

MW-6


Concentration (µg/l)
70
60
50
40
30
20
10
0
1/1/88
12/31/88
1/1/90
1/1/91
1/1/92
1/1/93
1/1/94
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
Groundwater Elevation (feet msl)
t-1,2-DCE
VCL
TCE
PCE
BEN
1,1-DCE
1,1-DCA
Groundwater Elevation

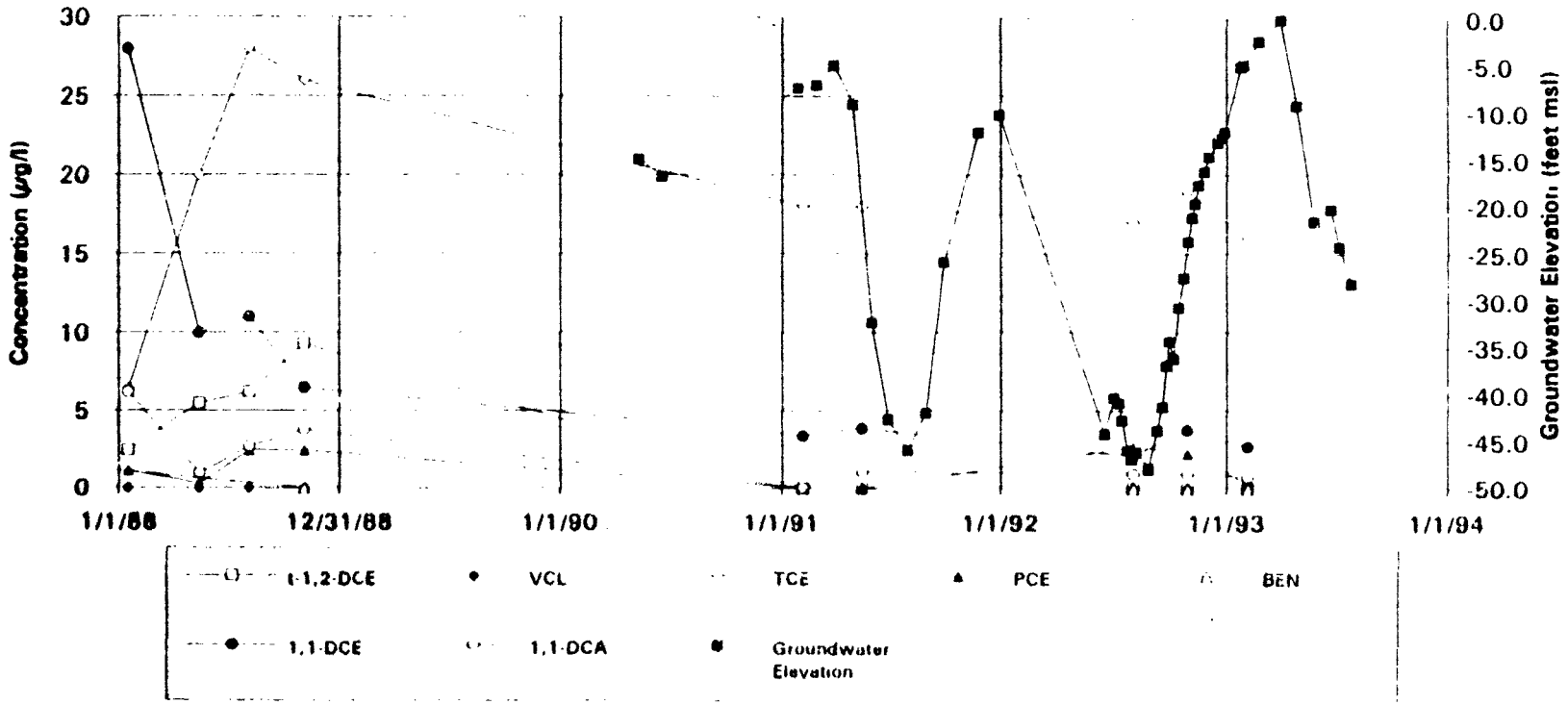
MW-7



G:\users\dr\emr\davis\MW-7.XLC

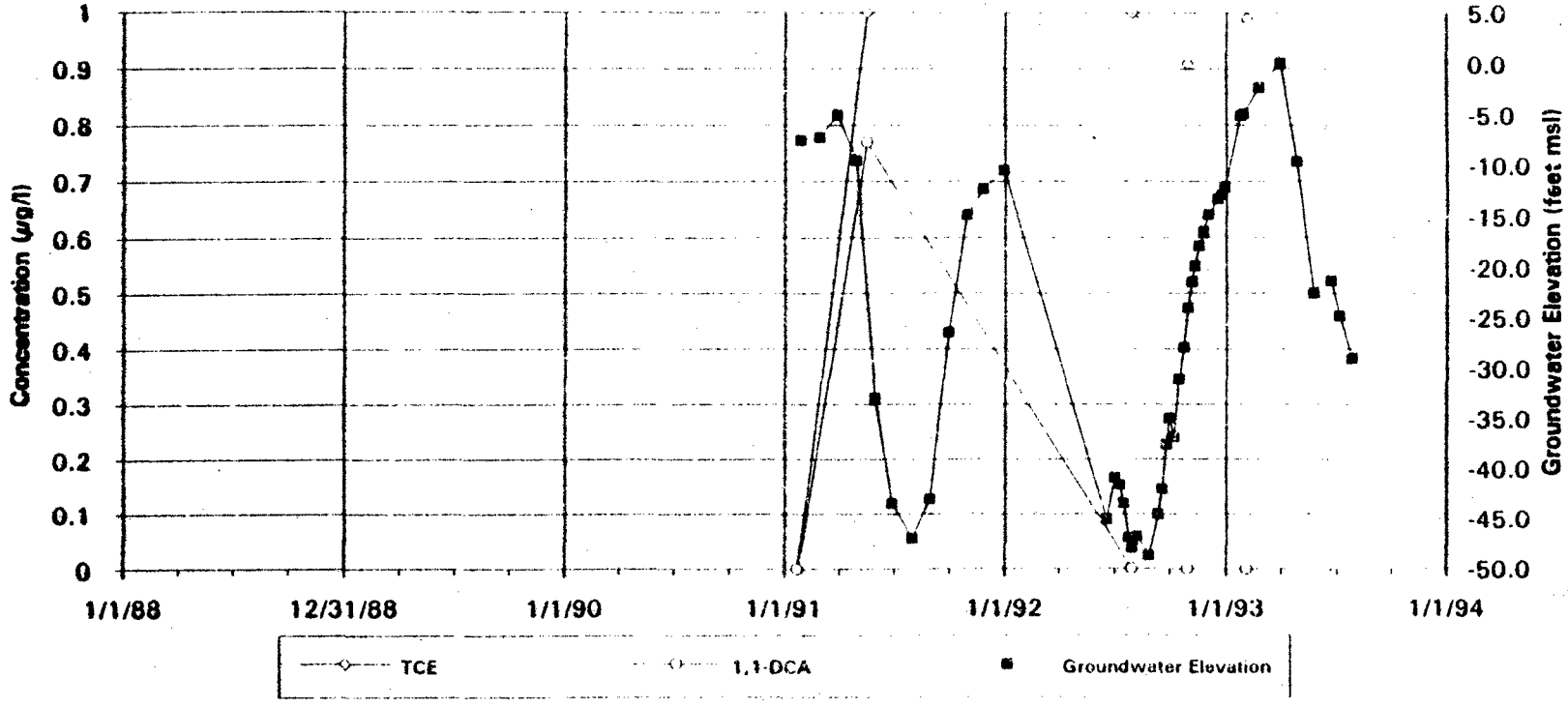
9/7/93

MW-8


Concentration (µg/l)
30
25
20
15
10
5
0
1/1/88
12/31/88
1/1/90
1/1/91
1/1/92
1/1/93
1/1/94
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
Groundwater Elevation (feet msl)
t-1,2-DCE
VCL
TCE
PCE
BEN
1,1-DCE
1,1-DCA
Groundwater Elevation

NOTE:
The following compounds were not detected:
1,1-DCE, BEN, PCE, VCL, t-1,2-DCE

MWB-14

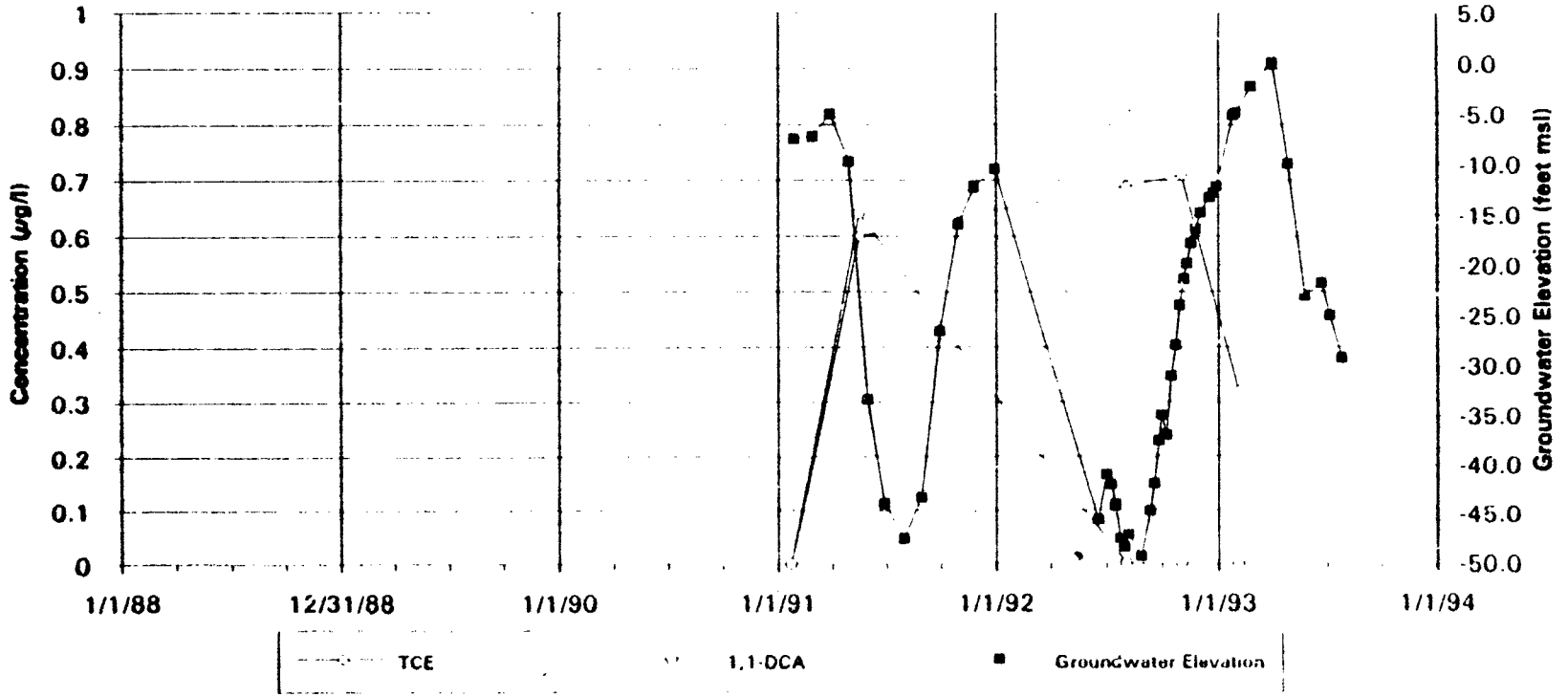


G:\users\da\emr\davis\MWB-14.XLC

9/8/93

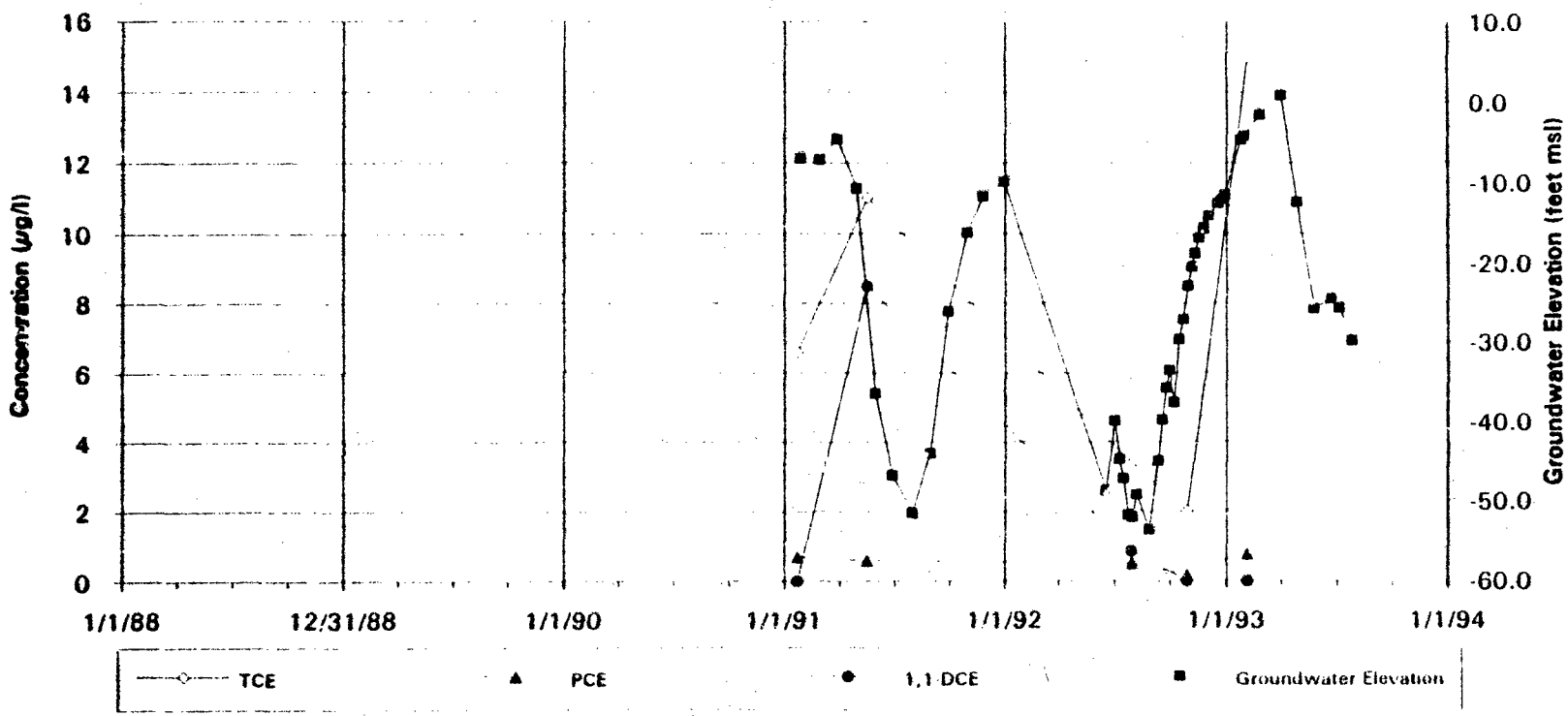
NOTE:
The following compounds were not detected:
1,1-DCE, BEN, PCE, VCL, t-1,2-DCE

MWC-14



NOTE:
The following compounds were not detected:
1,1-DCA, BEN, VCL, t-1,2-DCE

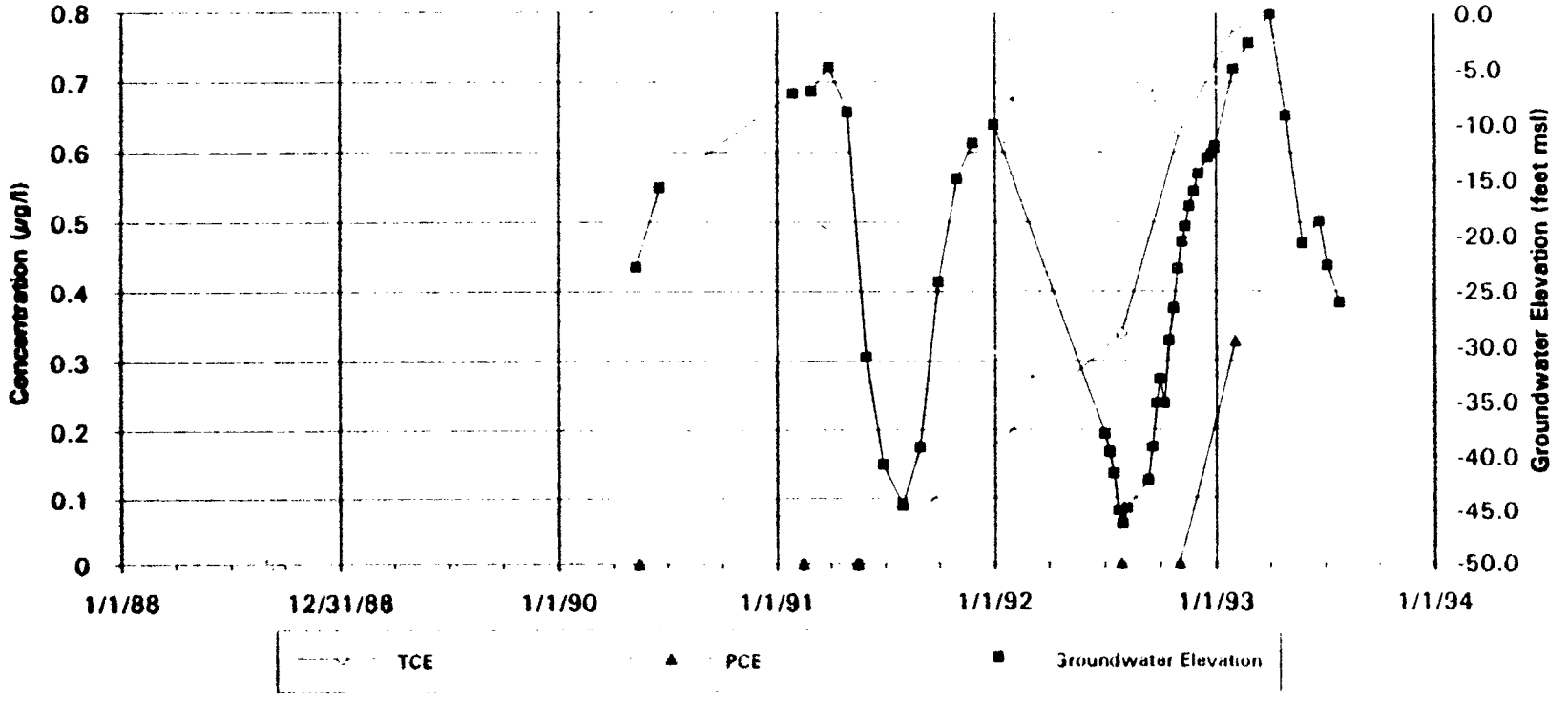
MWD-14



G:\users\data\emr\davis\MWD-14.XLC

9/8/93

NOTE:
The following compounds were not detected:
1,1-DCA, 1,1-DCE, BEN, VCL, t-1,2-DCE

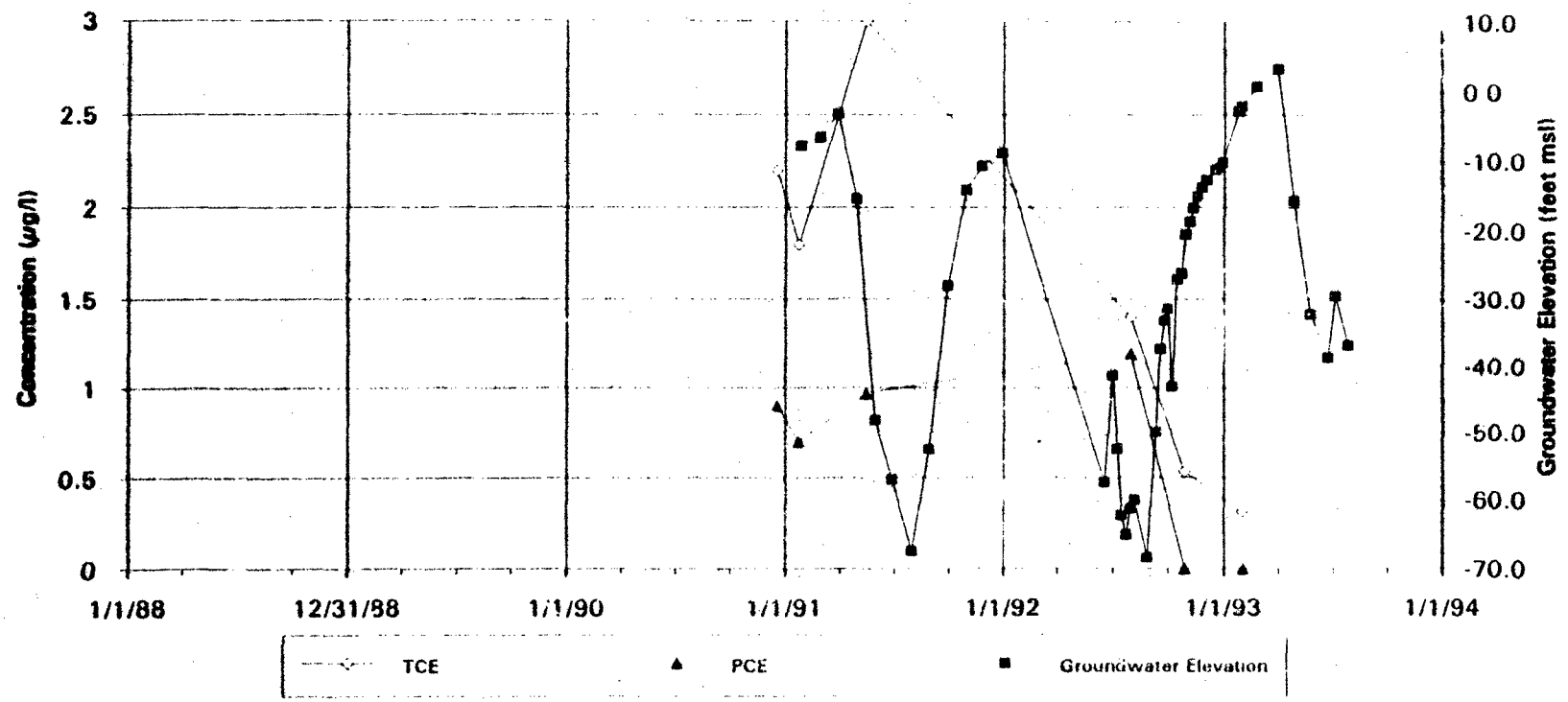


G:\users\data\mr\davis\MWD-2.XLC

9/7/93

NOTE:
The following compounds were not detected:
1,1-DCA, 1,1-DCE, BEN, VCL, t-1,2-DCE

MWE-3



G:\users\da\emr\davis\MWE-3.XLC

9/7/93

PREPARED FOR: Davis RI/FS Report

PREPARED BY: David Towell/CH2M HILL, Reno
Gerald Vogt/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Mass Estimates for Contaminants of Concern in the Saturated Zone
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.18

Purpose and Scope

The purpose of this technical memorandum is to describe the procedures used to estimate the mass of the contaminants of concern (COCs) that pose the greatest risk present in the saturated zone beneath the Davis Global Communications Site (Davis Site). The mass of contamination present in the subsurface is an important consideration for developing and evaluating potential remedial actions at the site. Contaminants in the saturated zone can be either dissolved in the groundwater or sorbed onto the aquifer or aquitard materials. The contaminant mass estimates presented in this technical memorandum incorporate both dissolved and sorbed contamination.

The primary COCs in the saturated zone at the site are all volatile organic compounds (VOCs). Specifically, they are the seven VOCs detected most frequently and with the greatest concentrations above maximum contaminant levels (MCLs) in groundwater samples from monitoring wells:

- Tetrachloroethene (PCE)
- Trichloroethene (TCE)
- 1,1-Dichloroethane (1,1-DCA)
- 1,1-Dichloroethene (1,1-DCE)
- 1,2-Dichloroethene, both the cis and trans isomers (1,2-DCE)
- Benzene
- Vinyl Chloride

Individual mass estimates have been made for each of these compounds in each of the distinct aquifers and aquitards present in the upper 200 feet of the saturated zone beneath the site. Four separate aquifers, each with a corresponding overlying aquitard, have been identified and delineated. The aquifers are designated the B, C, D,

and E aquifers. Within each of these aquifers, a target zone for remediation has been delineated based on the extent of contamination in that aquifer. The extent of contamination in each aquifer is based on contaminant data from groundwater monitoring wells screened exclusively in that aquifer. The target zones for each aquifer are shown in Figure F(a)-1 through F(a)-4. Water quality data from groundwater monitoring well samples taken during February and July 1993 are also shown on the figures along with contaminant contours.

Approach

Estimating the mass of contaminants in the saturated zone requires two basic data sets: data on the physical characteristics of the aquifers and aquitards of interest (e.g., area, thickness, porosity, soil density, and fractional organic carbon content [f_{oc}]) and data on the contaminant characteristics in the aquifers of interest (e.g., contaminant concentration, contaminant distribution, and water-organic carbon distribution coefficient [K_{oc}]).

Table F(a)-1 lists the source and range for each type of data gathered to complete the mass estimate for each of the COCs at the site. For each COC and each aquifer or aquitard, the values assumed for each parameter listed in Table F(a)-1 are provided along with the mass estimates in Tables F(a)-2 through F(a)-8 (one table for each of the seven COCs).

The following equation was used to estimate the dissolved mass of each COC in each aquifer and aquitard:

*Dissolved Contaminant Mass = target area volume * porosity * average contaminant concentration*

where: Target area volume = target area * target area thickness
Average contaminant concentrations = As described in Table F(a)-1 (Average Contaminant Distribution parameter)

To estimate the sorbed mass of each COC in each aquifer and aquitard, the following equation was used:

*Sorbed Contaminant Mass = target area soil mass * average contaminant concentration * Koc * foc*

where: Target area soil mass = target area volume * soil bulk density
Average contaminant concentrations = As described in Table F(a)-1 (Average Contaminant Distribution parameter)

These two equations are incorporated into Tables F(a)-2 through F(a)-8 to estimate the mass of each COC in the saturated zone beneath the site. Results and conclusions are discussed in the next section.

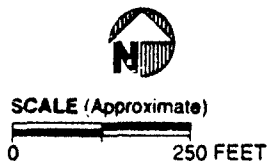
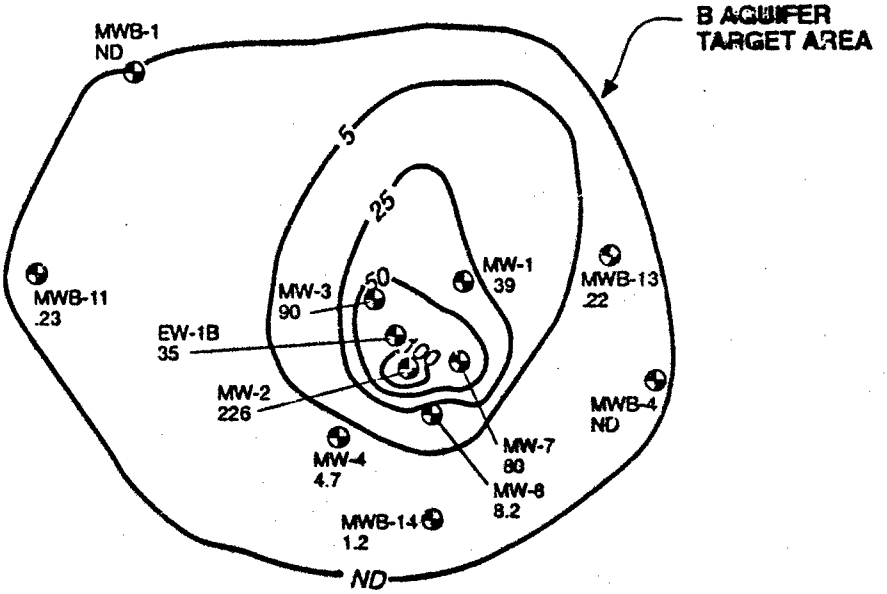


FIGURE F(a)
BASE FOR TARGET AREAS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

SAC2R/22 55 19

CH2M HILL



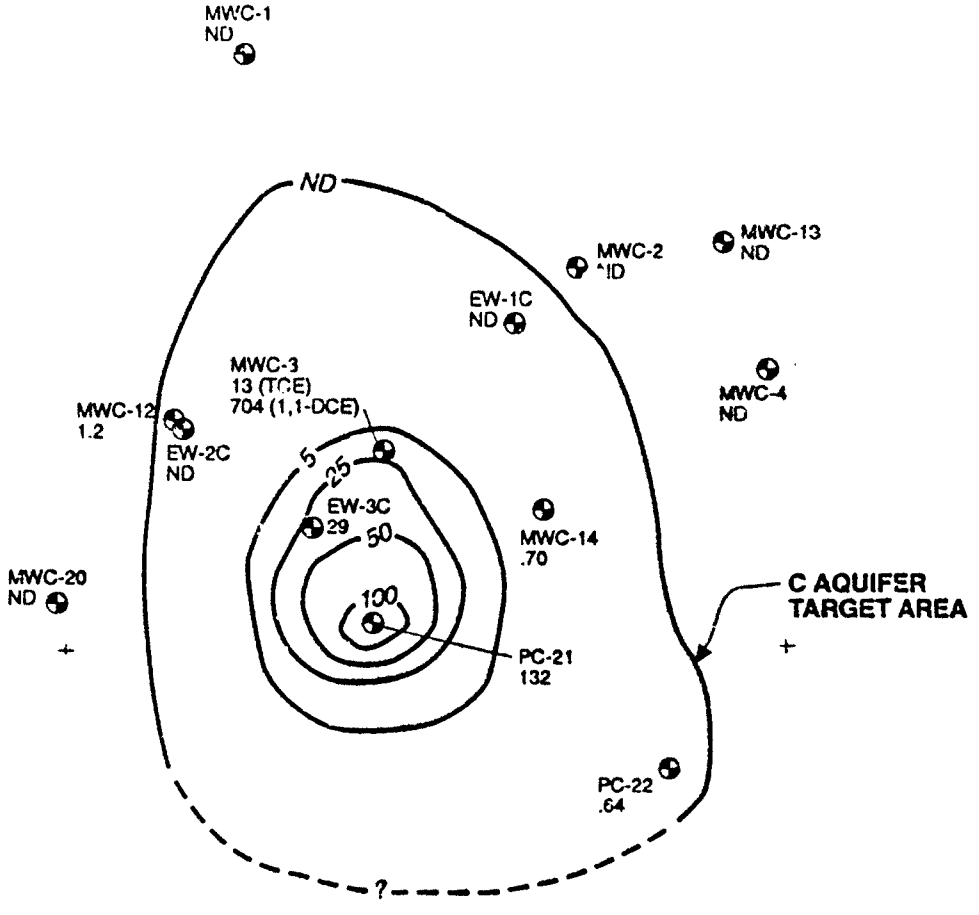
LEGEND

GROUNDWATER MONITORING WELL

5 B AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

FIGURE F(a)-1
B AQUIFER TARGET AREA
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_328
5055.19



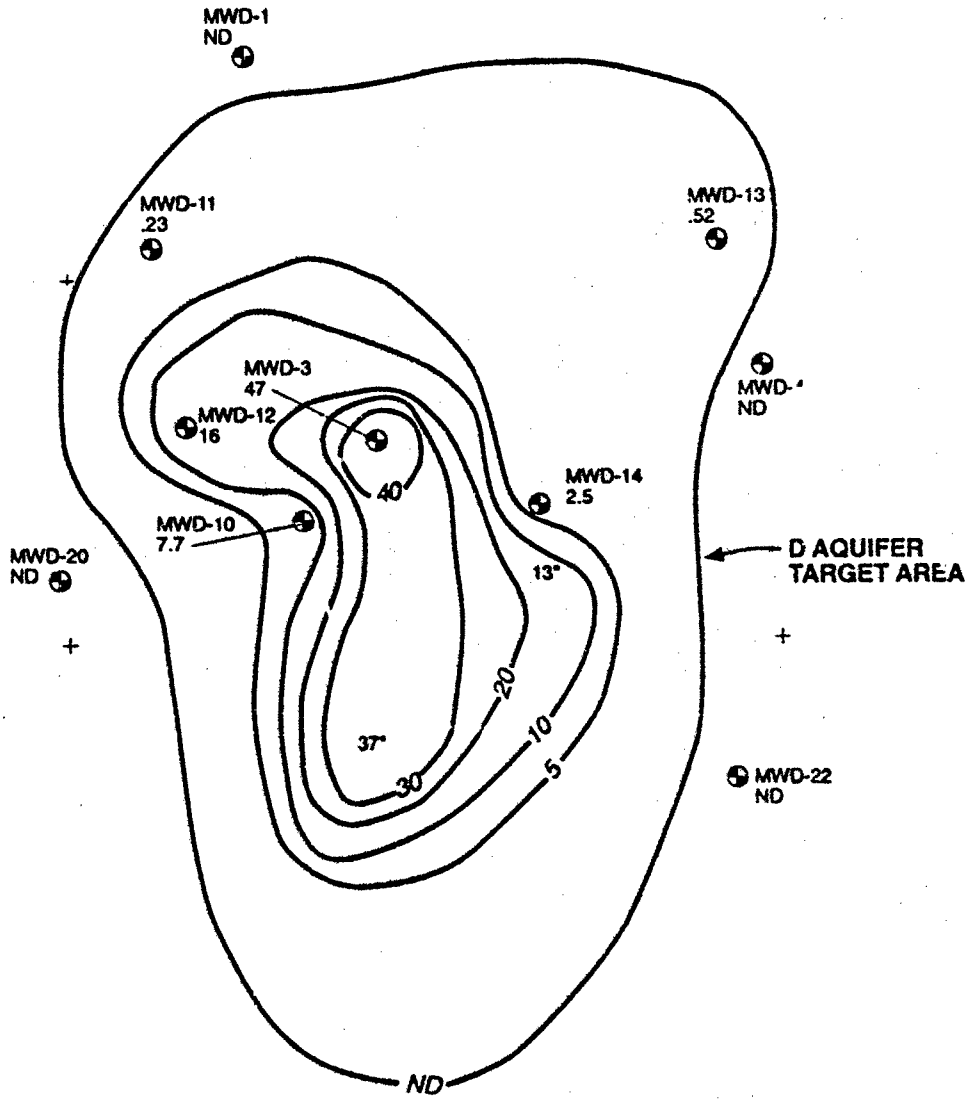
LEGEND

GROUNDWATER MONITORING WELL

5 C AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

FIGURE F(a)-2
C AQUIFER TARGET AREA
DAVIS GLOBAL COMMUNICATIONS SIT
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RODI:12_321
5055.19



LEGEND

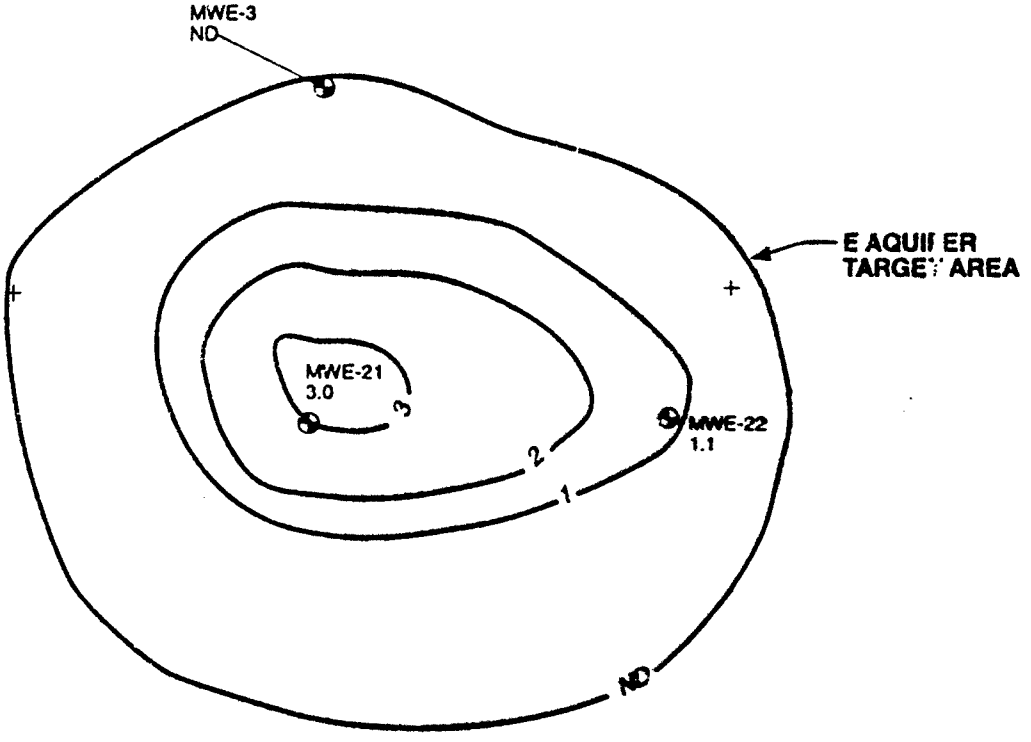
GROUNDWATER MONITORING WELL

30 D AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

* SAMPLES TAKEN DURING DRILLING

FIGURE F(a)-3
D AQUIFER TARGET AREA
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

HDD1412_322
5055 19



LEGEND

GROUNDWATER MONITORING WELL

3 E AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

FIGURE F(a)-4
E AQUIFER TARGET AREA
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

R001412.323
5056.19

Table F(a)-1
Data Sources for Contaminant Mass Estimates

Parameter	Parameter Range of Values	Data Source
Target Area (ft^2)	B: 453,000 C: 649,350 D: 969,000 E: 950,000	Delineated on the basis of the areal extent of contaminants detected in groundwater samples from each aquifer. Target areas for aquitards are assumed to match the target area of the underlying aquifer.
Aquifer or Aquitard Thickness (ft)	A-B: 25 B-C, C-D, D-E: 20 B, C, D, E: 30	Estimated from review of lithologic data collected during installation of monitoring wells at the site. In most cases, the aquifer and aquitard thickness varies across the site. The value presented is an estimated average thickness.
Porosity	A-B, B-C, C-D, D-E: 0.45 B: 0.40 C: 0.39 D, E: 0.35	Based on typical values for the specific soil types present in each aquifer and aquitard. Porosity was measured on C and E aquifer samples. The data are presented in Appendix D, Summary of Field Activity.
Soil Bulk Density (gm/cm^3)	All zones: 1.45	Based on average laboratory analyses of samples collected during drilling at the site.
f_{oc}	A-B, B-C: 0.002 C-D, D-E: 0.001 B: 0.0025 C: 0.001 D: 0.0008 E: 0.0007	Based on laboratory results from total organic carbon analyses.
Contaminant Concentrations	Varies per aquifer and contaminant	Based on analytical results from the February 1993 and July 1993 groundwater sampling event. Analytical results from these sampling events can be found in Appendix U.
Average Contaminant Distribution (in each Aquifer and Aquitard)		Each aquifer target area (described above) was divided into polygons that approximate the portion of the target area represented by data from each groundwater monitoring well. Contaminant concentrations in individual polygons were assigned based on the February 1993 and July 1993 sampling data for the well representing that polygon. Average, aquifer-wide concentrations were estimated by totaling the weighted concentrations from individual polygons (based on the relative size of each polygon). Average concentrations in each aquitard are assumed to equal the difference divided by two in the concentrations estimated for the underlying and overlying aquifers. The raw data tables and polygon areas are attached at the end of this technical memorandum.
K_{oc} (cm^3/gm)	PCE: 364 TCE: 126 1,1-DCA: 30 1,1-DCE: 65 1,2-DCE: 59 Benzene: 71 Vinyl Chloride: 8	Values obtained from EPA's *Subsurface Contamination Guide*, EPA/540/2-90/011, October 1990.

Table F(a)-2 PCE Mass Estimate											
Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A B	453,000	25	11,325,000	0.45	72.8	364	0.002	10.50	24.61	35.11
65	B	453,000	30	13,590,000	0.40	72.8	364	0.0025	11.20	36.91	48.12
95	B C	649,350	20	12,987,000	0.45	37.0	364	0.002	6.12	14.34	20.46
115	C	649,350	36	19,480,500	0.39	2.1	364	0.001	0.45	0.61	1.06
145	C D	969,000	20	19,380,000	0.45	2.9	364	0.001	0.72	0.84	1.55
165	D	969,000	30	29,070,000	0.35	3.6	364	0.0008	1.04	1.25	2.29
195	D E	950,000	20	19,000,000	0.45	1.8	364	0.001	0.96	0.51	1.47
215	E	950,000	30	28,500,000	0.35	0.0	364	0.0007	0.00	0.00	0.00
								Total	**31.00**	**79.07**	
								Total Dissolved and Sorbed			**110.07**

Table F(a)-3
TCE Mass Estimate

Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A-B	453,000	25	11,325,000	0.45	53.70	126	0.002	7.75	6.28	14.03
65	B	453,000	30	13,590,000	0.43	53.70	126	0.0025	8.26	9.43	17.69
95	B-C	649,350	20	12,987,000	0.45	37.0	126	0.002	6.12	4.96	11.09
115	C	649,350	30	19,480,500	0.39	20.0	126	0.001	4.30	2.01	6.31
145	C-D	969,000	20	19,380,000	0.45	16.5	126	0.001	4.07	1.65	5.73
165	D	969,000	30	29,070,000	0.35	13.0	126	0.0008	3.74	1.56	5.31
195	D-E	950,000	20	19,000,000	0.45	6.0	126	0.001	1.45	0.59	2.04
215	E	950,000	30	28,500,000	0.35	0.3	126	0.0007	0.08	0.03	0.12
								Total	35.79	26.52	
								Total Dissolved and Sorbed			62.31

Table F(a)-4
1,1-DCA Mass Estimate

Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A-B	453,000	25	11,325,000	0.45	0.03	30	0.002	0.00	0.00	0.01
65	B	453,000	30	13,590,000	0.40	0.03	30	0.00025	0.00	0.00	0.01
95	B-C	649,350	20	12,987,000	0.45	0.0	30	0.002	0.00	0.00	0.00
115	C	649,350	30	19,480,500	0.39	0.0	30	0.001	0.00	0.00	0.00
145	C-D	969,000	20	19,380,000	0.45	0.0	30	0.001	0.00	0.00	0.00
165	D	969,000	30	29,070,000	0.35	0.0	30	0.0008	0.00	0.00	0.00
195	D-E	950,000	20	19,000,000	0.45	0.0	30	0.001	0.00	0.00	0.00
215	E	950,000	30	28,500,000	0.35	0.0	30	0.0007	0.00	0.00	0.00
								Total	**0.01**	**0.00**	
								Total Dissolved and Sorbed			**0.01**

Table F(a)-5
1,1-DCE Mass Estimate

Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A-B	453,000	25	11,325,000	0.45	14.4	65	0.002	2.08	0.87	2.95
65	B	453,000	30	13,590,000	0.40	14.4	65	0.0025	2.22	1.30	3.52
95	B-C	649,350	20	12,987,000	0.45	31.0	65	0.002	11.31	2.15	13.46
115	C	649,350	30	19,480,500	0.39	48.4	65	0.001	22.96	2.51	25.47
145	C-D	969,000	20	19,380,000	0.45	29.0	65	0.001	15.79	1.50	17.29
165	D	969,000	30	29,070,000	0.35	11.3	65	0.0008	7.18	0.70	7.88
195	D-E	950,000	20	19,000,000	0.45	5.5	65	0.001	2.94	0.28	3.21
215	E	950,000	30	28,500,000	0.35	0.0	65	0.0007	0.00	0.00	0.00
								Total	**64.46**	**9.31**	
								Total Dissolved and Sorbed			**73.77**

Table F(a)-6 1,2-DCE (cis and trans) Mass Estimate											
Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A-B	453,000	25	11,325,000	0.45	47.6	59	0.002	6.87	2.61	9.48
65	B	453,000	30	13,590,000	0.40	47.6	59	0.0025	7.33	3.51	10.84
95	B-C	649,350	20	12,987,000	0.45	25.0	59	0.002	4.14	1.41	5.55
115	C	649,350	30	19,480,500	0.39	3.5	59	0.001	0.75	0.15	0.90
145	C-D	969,000	20	19,380,000	0.45	2.9	59	0.001	0.72	0.12	0.84
165	D	969,000	30	29,070,000	0.35	1.2	59	0.0008	0.35	0.06	0.41
195	D-E	950,000	20	19,000,000	0.45	0.6	59	0.001	0.32	0.05	0.37
215	E	950,000	30	28,500,000	0.35	0.0	59	0.0007	0.00	0.00	0.00
								Total	20.46	7.91	
								Total Dissolved and Sorbed			28.38

Table F(a)-7
Benzene Mass Estimate

Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A-B	453,000	25	11,325,000	0.45	0.1	71	0.002	0.02	0.01	0.03
65	B	453,000	30	13,590,000	0.40	0.1	71	0.0025	0.02	0.01	0.04
95	B-C	649,350	20	12,987,000	0.45	0.1	71	0.002	0.03	0.01	0.03
115	C	649,350	30	19,480,500	0.32	0.0	71	0.001	0.00	0.00	0.00
145	C-D	969,000	20	19,380,000	0.45	0.0	71	0.0008	0.00	0.00	0.00
165	D	969,000	30	29,070,000	0.30	0.0	71	0.001	0.00	0.00	0.00
195	D-E	950,000	20	19,000,000	0.45	0.0	71	0.0007	0.00	0.00	0.00
215	E	950,000	30	28,500,000	0.30	0.0	30	0.0005	0.00	0.00	0.00
								Total	**0.07**	**0.03**	
								Total Dissolved and Sorbed			**0.10**

Table F(a)-8
Vinyl Chloride Mass Estimate

Depth to Top of Unit	Aquifer/ Aquitard	Target Area (ft^2)	Target Area Thickness (ft)	Target Area Volume (ft^3)	Porosity	VOC Concentration (µg/l)	Assumed Koc	Assumed foc	Dissolved Contaminant Mass (kg)	Sorbed Contaminant Mass (kg)	Total
40	A-B	453,000	25	11,325,000	0.45	9.3	8	0.002	1.34	0.07	1.41
65	B	453,000	30	13,590,000	0.40	9.3	8	0.0025	1.43	0.09	1.52
95	B-C	649,350	20	12,987,000	0.45	4.6	8	0.002	1.68	0.08	1.76
115	C	649,350	30	19,480,500	0.39	0.0	8	0.001	0.00	0.00	0.00
145	C-D	969,000	20	19,380,000	0.45	0.0	8	0.001	0.00	0.00	0.00
165	D	969,000	30	29,070,000	0.35	0.0	8	0.0008	0.00	0.00	0.00
195	D-E	950,000	20	19,000,000	0.45	0.0	8	0.001	0.00	0.00	0.00
215	E	950,000	30	28,500,000	0.35	0.0	8	0.0007	0.00	0.00	0.00
								Total	4.45	0.24	
								Total Dissolved and Sorbed			4.69

Results and Conclusions

The mass estimates developed using the data and equations described above are discussed in this section. Tables F(a)-2 through F(a)-8 contain total in-place mass estimates for the individual COCs. The tables include separate estimates for each COC in each individual aquifer and aquitard. Mass estimates from these tables are summarized in Tables F(a)-9 and F(a)-10.

As indicated in Table F(a)-9, PCE and TCE account for more than 60 percent of the total mass present in the saturated zone beneath the site. In addition, these two compounds account for more than 85 percent of the sorbed mass of contaminants. The only other COCs present in significant quantities are 1,1-DCE and cis+trans-1,2-DCE (Table F(a)-9).

The vertical distribution of contamination can be evaluated by comparing the estimated contaminant mass values for aquifers B through E, which are successively deeper. Table F(a)-10 lists the estimated contaminant mass for each aquifer and aquitard. Table F(a)-10 indicates that over 82 percent of the estimated mass is present above the C-D aquitard (aquifers B and C and aquitards A-B and B-C). The limited contaminant mass present in the deeper units indicates that, while some downward migration of contaminants is occurring, the layering present in the aquifer system is inhibiting significant vertical contaminant migration. It should be noted that the mass estimates for the C, D, and E aquifers are considerably less reliable than the B aquifer estimates because of the smaller number of data points (monitoring wells).

In general, of the parameters used in the contaminant mass equations (listed in Table F(a)-1), the average contaminant concentration estimates and the fractional organic carbon content are the parameters with the greatest degree of uncertainty. This uncertainty can be attributed to uncertainty in the actual distribution of contamination and organic carbon content in aquifers resulting from the natural heterogeneity of the aquifers in the area and the relative scarcity of data points in some areas and depths (which results in larger distances between the wells and a less accurate estimate of average concentrations).

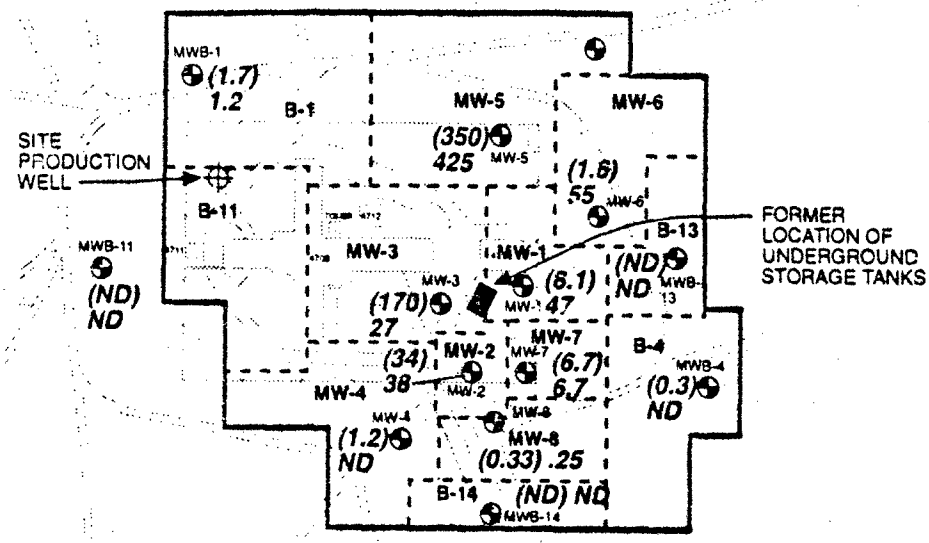
Table F(a) 9

Groundwater Mass Estimate

Contaminant of Concern	A-B		B		B-C		C		C-D		D		D-E		E		Contaminant Mass						Percent	Percent of Total	
	Dissolved	Sorbed	Dissolved	Sorbed	Dissolved	Sorbed	Dissolved	Sorbed	Dissolved	Sorbed	Dissolved	Sorbed	Dissolved	Sorbed	Dissolved	Sorbed	Total (kg) Dissolved	(lbs)	Sorbed	(lbs)	Total	(lbs)	of Total	Dissolved	Sorbed
Trichloroethene (TCE)	7.80	0.50	8.30	9.40	6.10	5.00	4.30	2.00	4.10	1.70	3.70	1.60	1.50	0.60	0.10	0.03	35.90	79.16	26.63	58.72	82.53	137.88	0.223	0.230	0.215
Tetrachloroethene (PCE)	10.50	23.80	14.20	17.00	6.10	14.10	0.40	0.60	0.70	0.80	1.00	1.30	1.00	0.50	0.00	0.00	30.90	68.13	79.30	175.30	110.40	243.45	0.394	0.198	0.643
1,2-Dichloroethene	6.90	2.60	7.30	3.20	4.10	1.40	0.80	0.20	0.70	0.10	0.40	0.06	0.30	0.03	0.00	0.00	20.50	45.20	7.91	17.44	28.41	62.64	0.102	0.131	0.064
1,1-Dichloroethene	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.000	0.000	0.000
1,1-Dichloroethane	2.10	0.90	2.20	1.30	11.30	2.10	23.00	2.30	15.80	1.50	7.20	0.70	2.90	0.30	0.00	0.00	64.50	142.22	9.30	20.51	73.80	162.73	0.264	0.413	0.075
Vinyl Chloride	1.30	0.07	1.40	0.08	1.70	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.40	9.70	0.24	0.53	4.64	10.23	0.017	0.028	0.002
Benzene	0.02	0.01	0.02	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.13	0.03	0.07	0.10	0.22	0.000	0.000	0.000
Total (kg)	28.62	34.88	30.43	51.30	29.33	23.89	28.50	5.30	21.30	4.10	12.30	3.66	5.70	1.45	0.10	0.03	156.28	344.66	123.61	272.56	279.89	617.16	1.000	1.000	1.000
Total (lbs)	63.11	76.91	67.10	113.12	64.67	52.67	62.84	11.69	46.97	9.04	27.12	8.07	12.57	3.20	0.22	0.07									
Percent of Total	0.10	0.28	0.19	0.42	0.19	0.19	0.18	0.04	0.14	0.03	0.08	0.03	0.04	0.01	0.00	0.00									
Total All Zones Dissolved (kg) (lbs)		156.28	344.66																						
Total All Zones Sorbed (kg) (lbs)		123.61	272.56																						

Table F(a)-10 Cumulative Groundwater Contaminant Mass (lb/kg)					
Contaminant of Concern	Dissolved	Sorbed	Total Per Zone	Cumulative Mass (kg)	Cumulative Percentage
A-B	63.1/28.6	76.9/34.9	140/63.5	140/63.5	22.7
B	67.1/30.43	113/51.3	180/81.73	320/145	51.8
B-C	64.6/29.3	50.5/22.9	115/52.2	435/197	70.4
C	62.8/28.5	11.7/5.3	74.5/33.8	510/231	82.5
C-D	47.0/21.3	9.0/4.1	56/25.4	566/257	91.6
D	27.1/12.3	8.1/3.7	35.2/16.0	601/272	97.2
D-E	12.6/5.7	3.2/1.4	15.8/7.1	617/279	99.8
E	.22/.1	.07/.03	.29/.13	618/280	100.00
Total (kg)	345/156	273/124	618/280	618/280	

Attachment F(a)-1
B Aquifer



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

N

SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 1
B AQUIFER POLYGON AREA
PCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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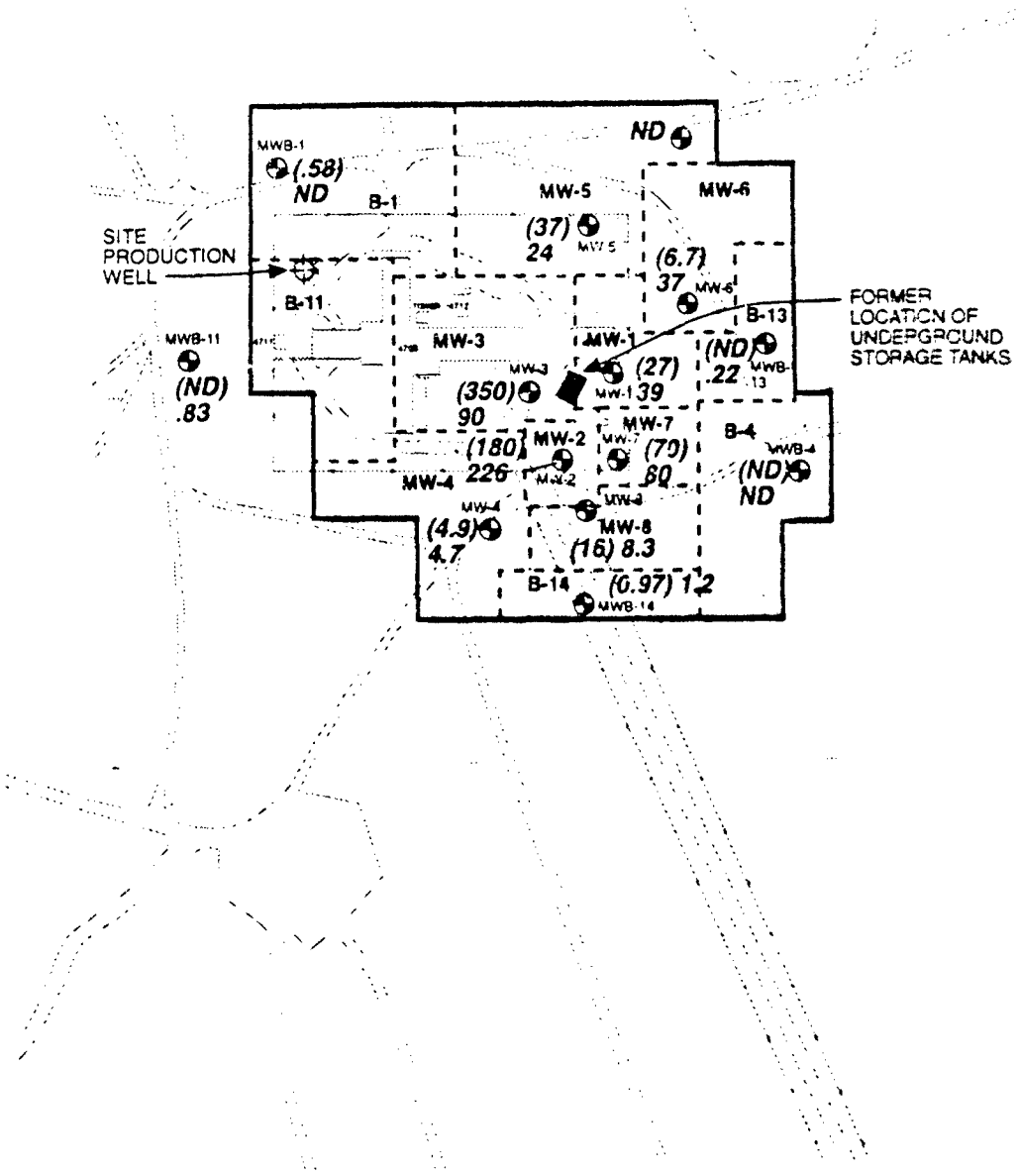
5055.19

CH2MHILL



EGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND NONDETECT (2/93), 7/93

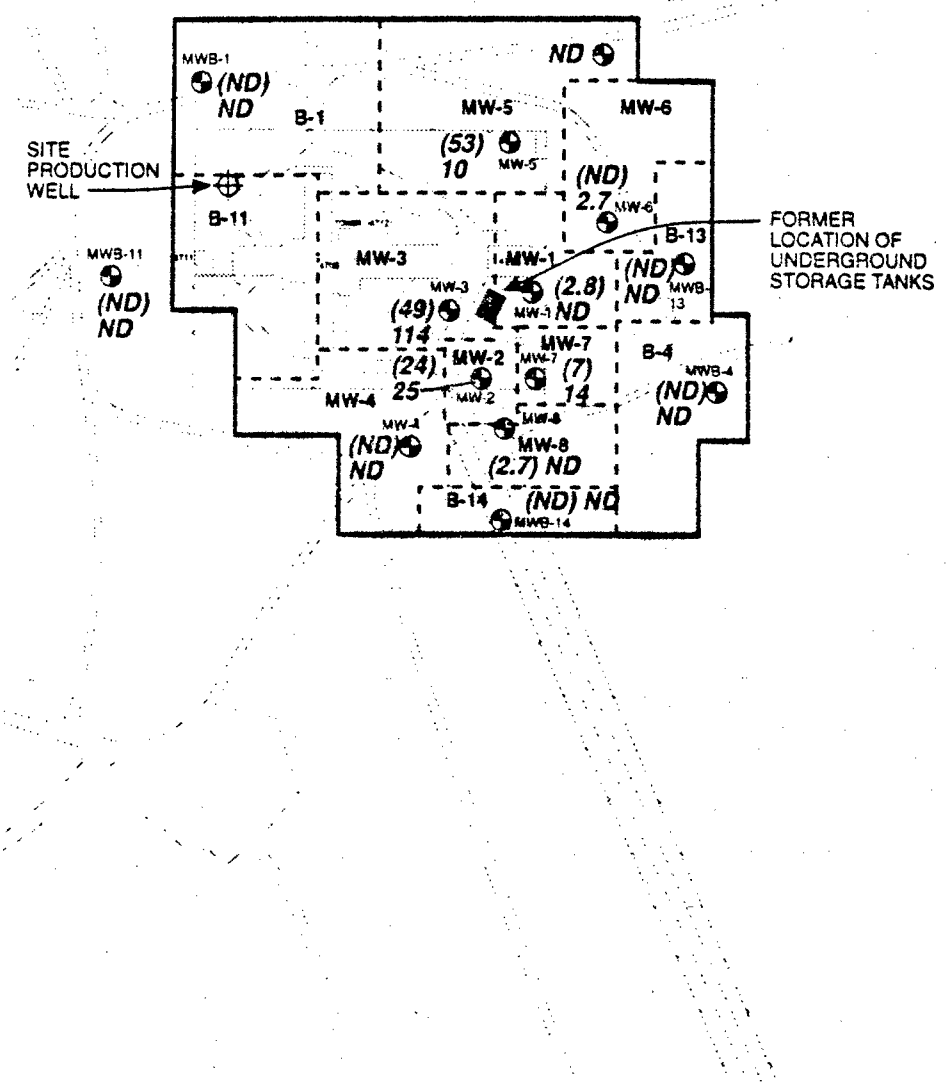
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 2
B AQUIFER POLYGON AREA
TCE CONCENTRACTIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

412.288
19



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

N

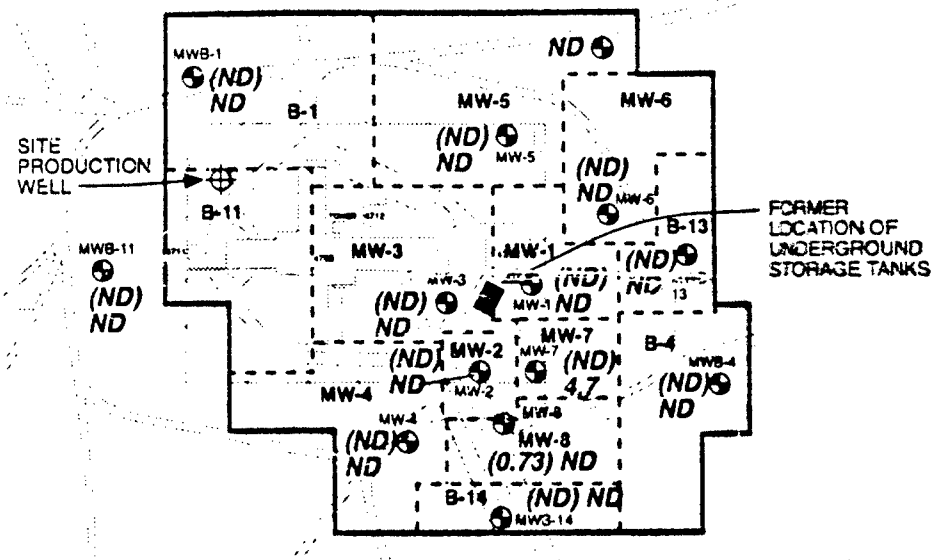
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 3
B AQUIFER POLYGON AREA
1,1-DCE CONCENTRACTIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412 287
5055 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

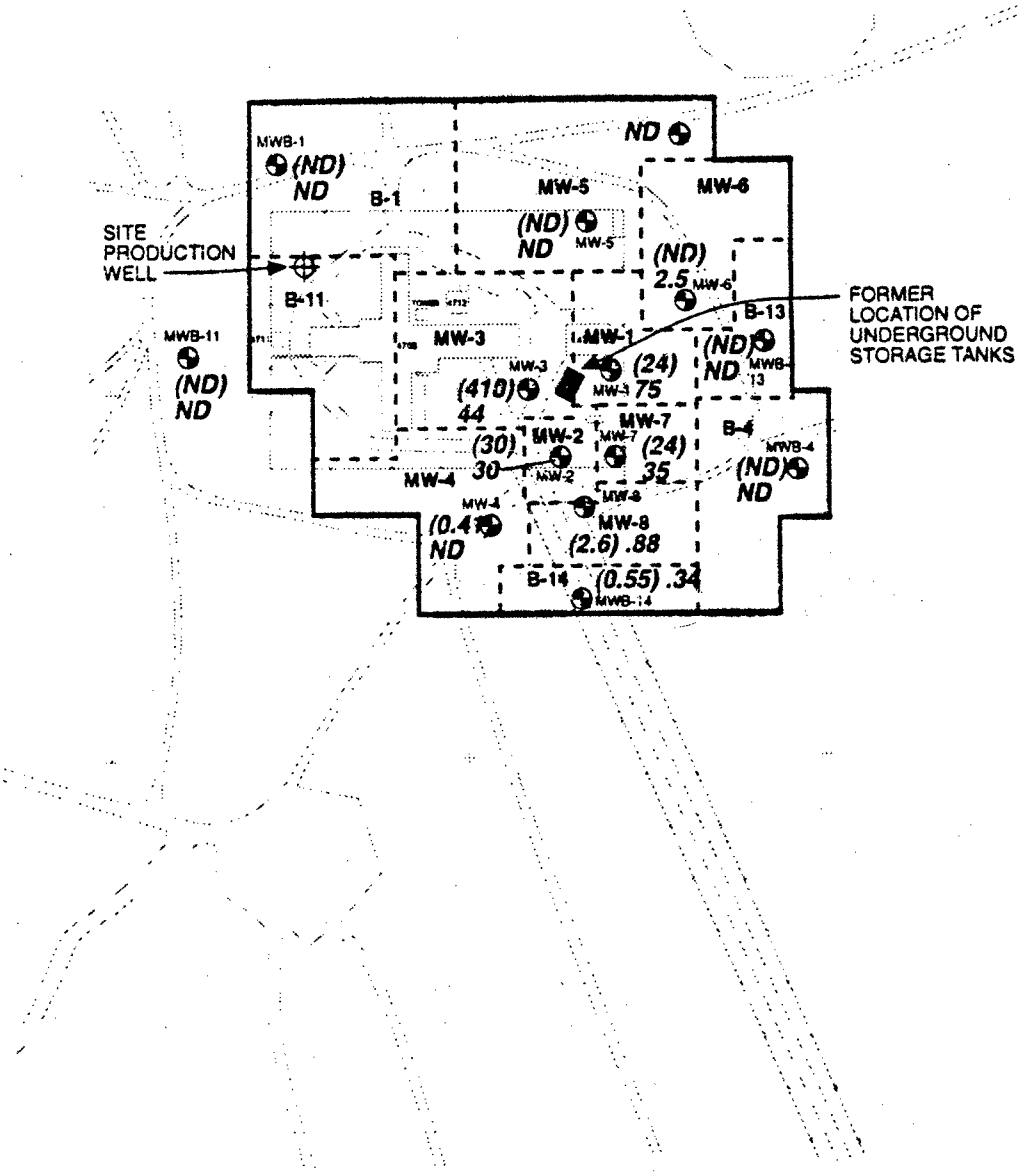
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 4
B AQUIFER POLYGON AREA
1,1-DCA CONCENTRACTIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RCO1413 288
5/55 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

N

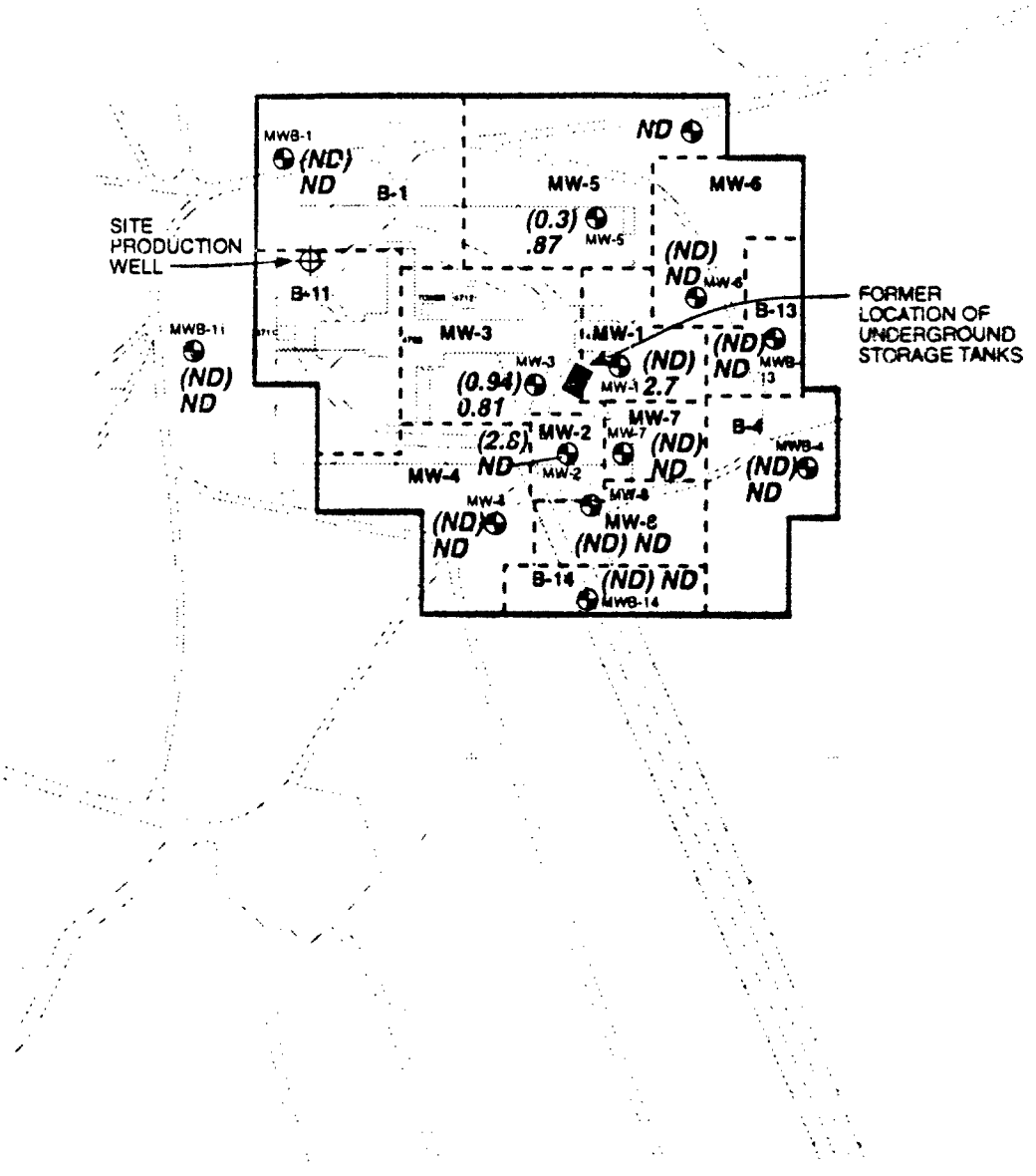
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 5
B AQUIFER POLYGON AREA
1,2-DCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412.200
5055.19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

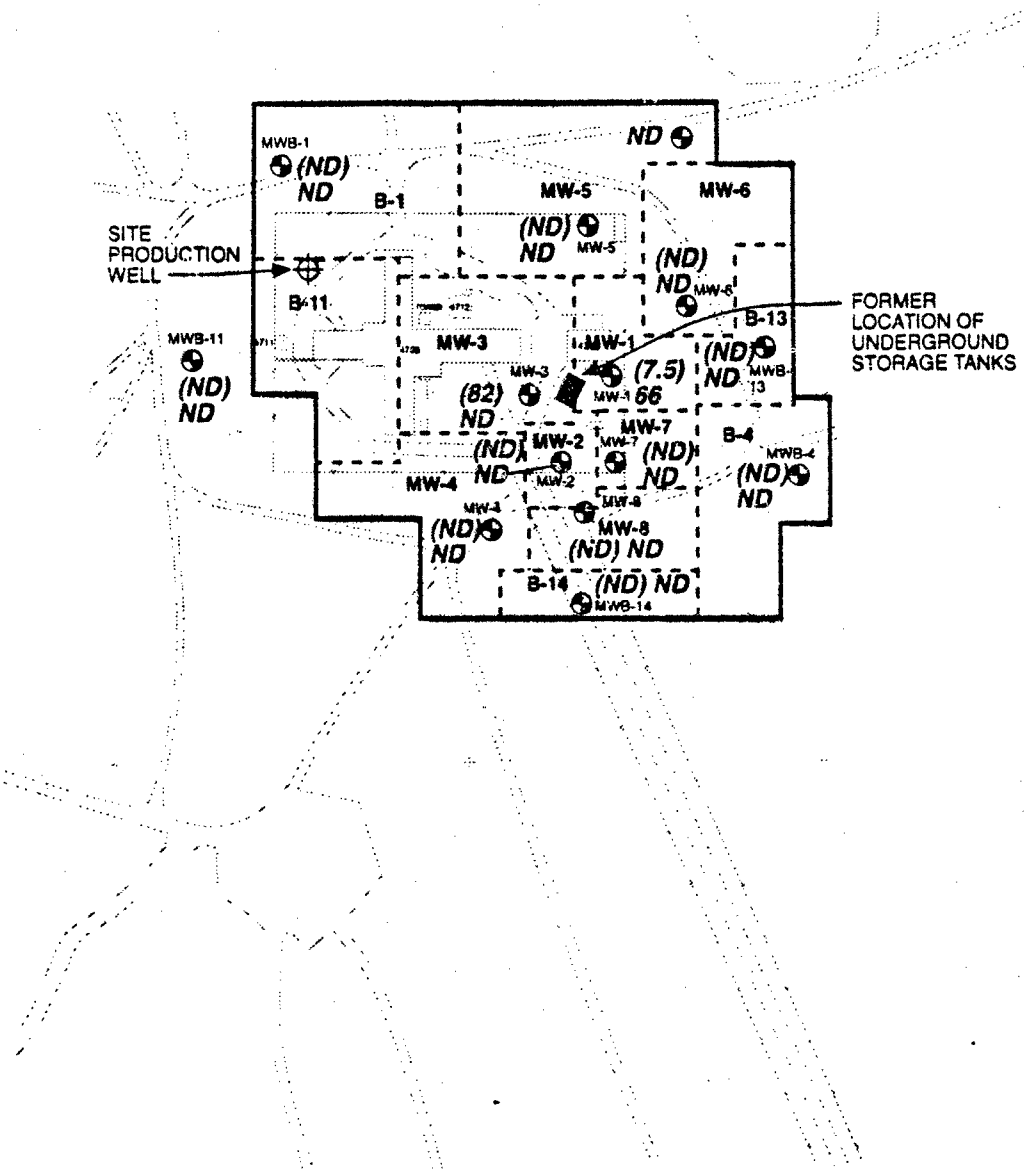
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 6
B AQUIFER POLYGON AREA
BENZENE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

DO1412.2B0
958 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

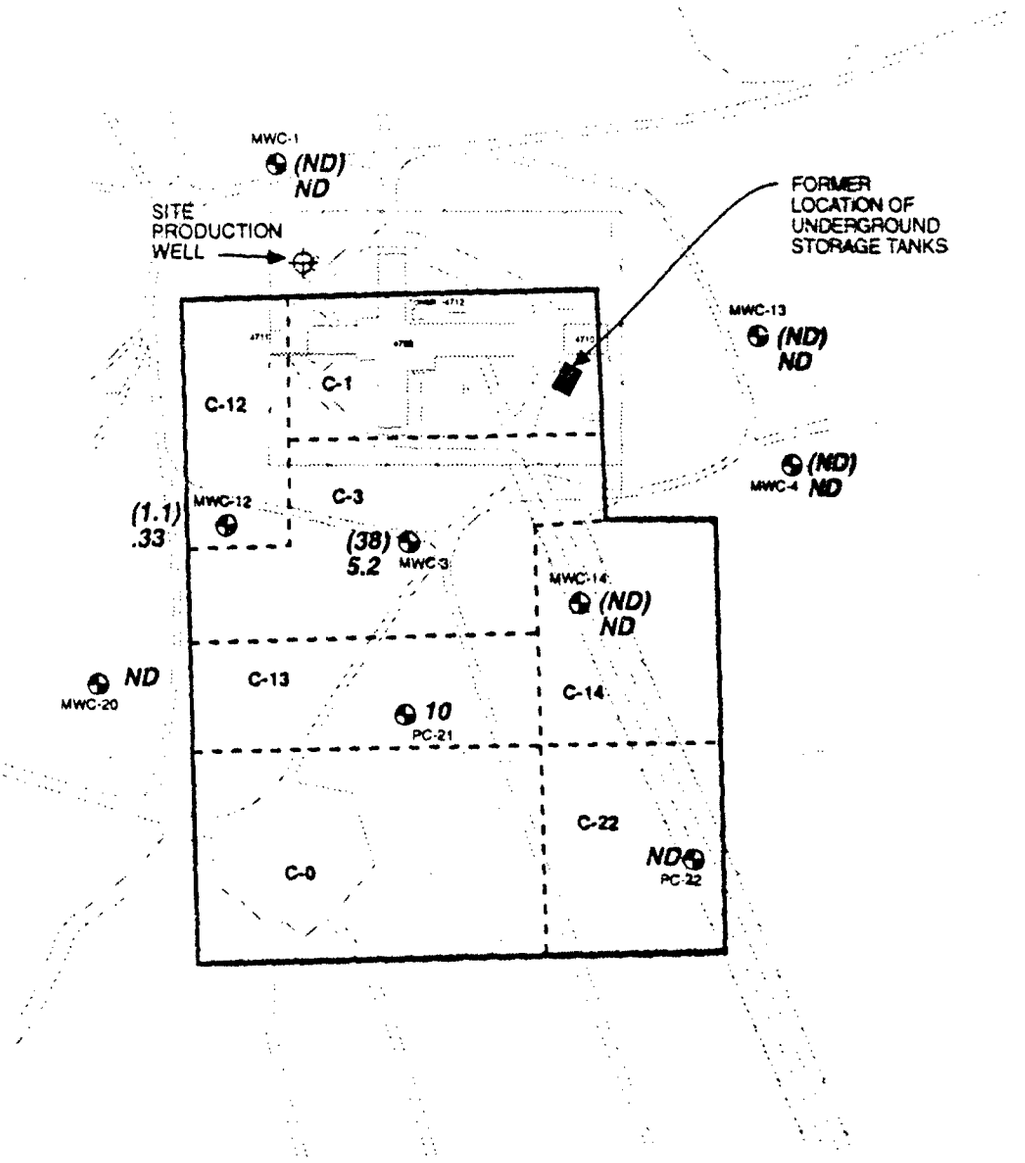
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 7
B AQUIFER POLYGON AREA
VCL-CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

R001218 291
SAC28722 55 10

CHEMHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

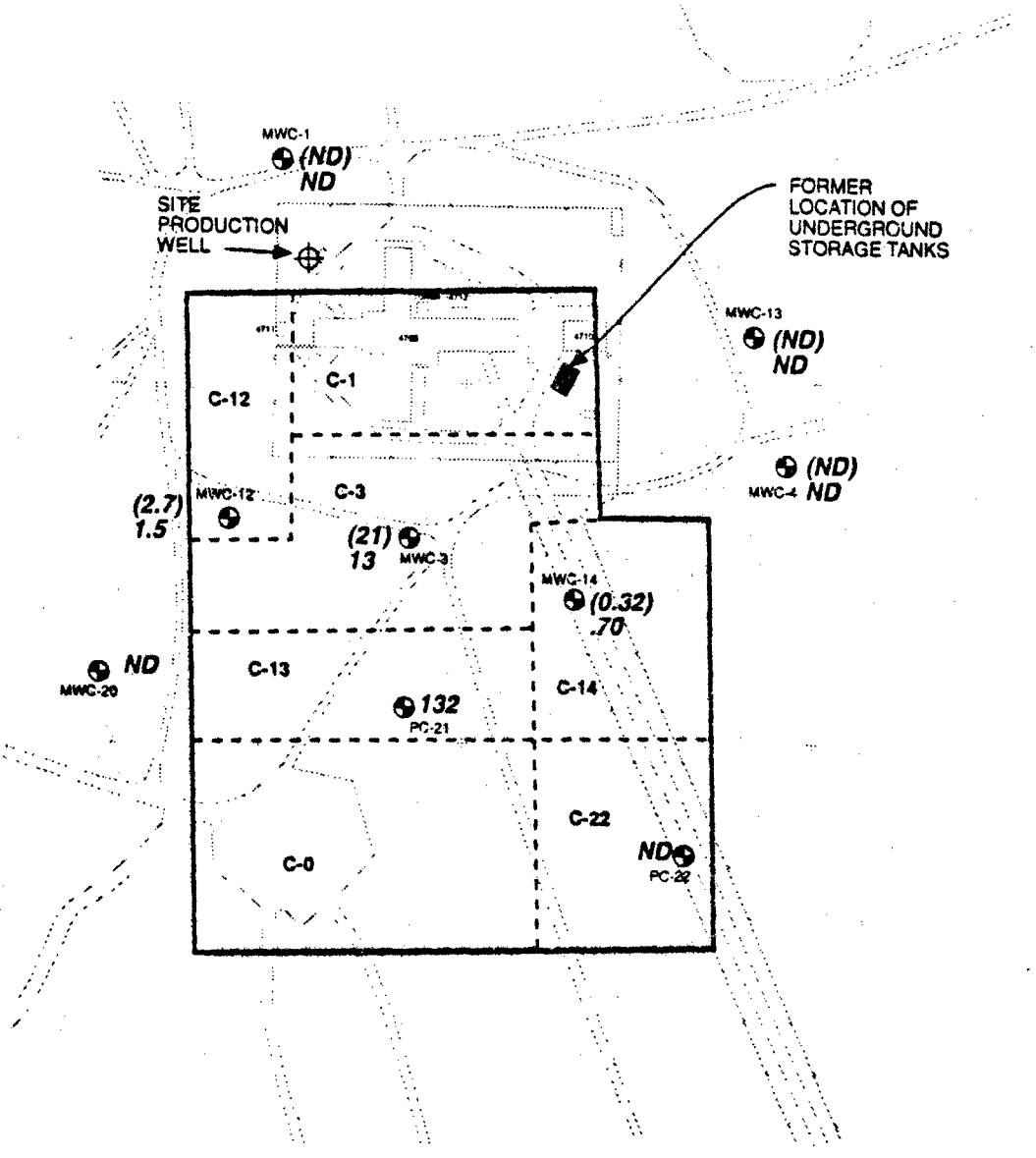
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 8
C AQUIFER POLYGON AREAS
PCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

ROD1412_282
5058 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

N

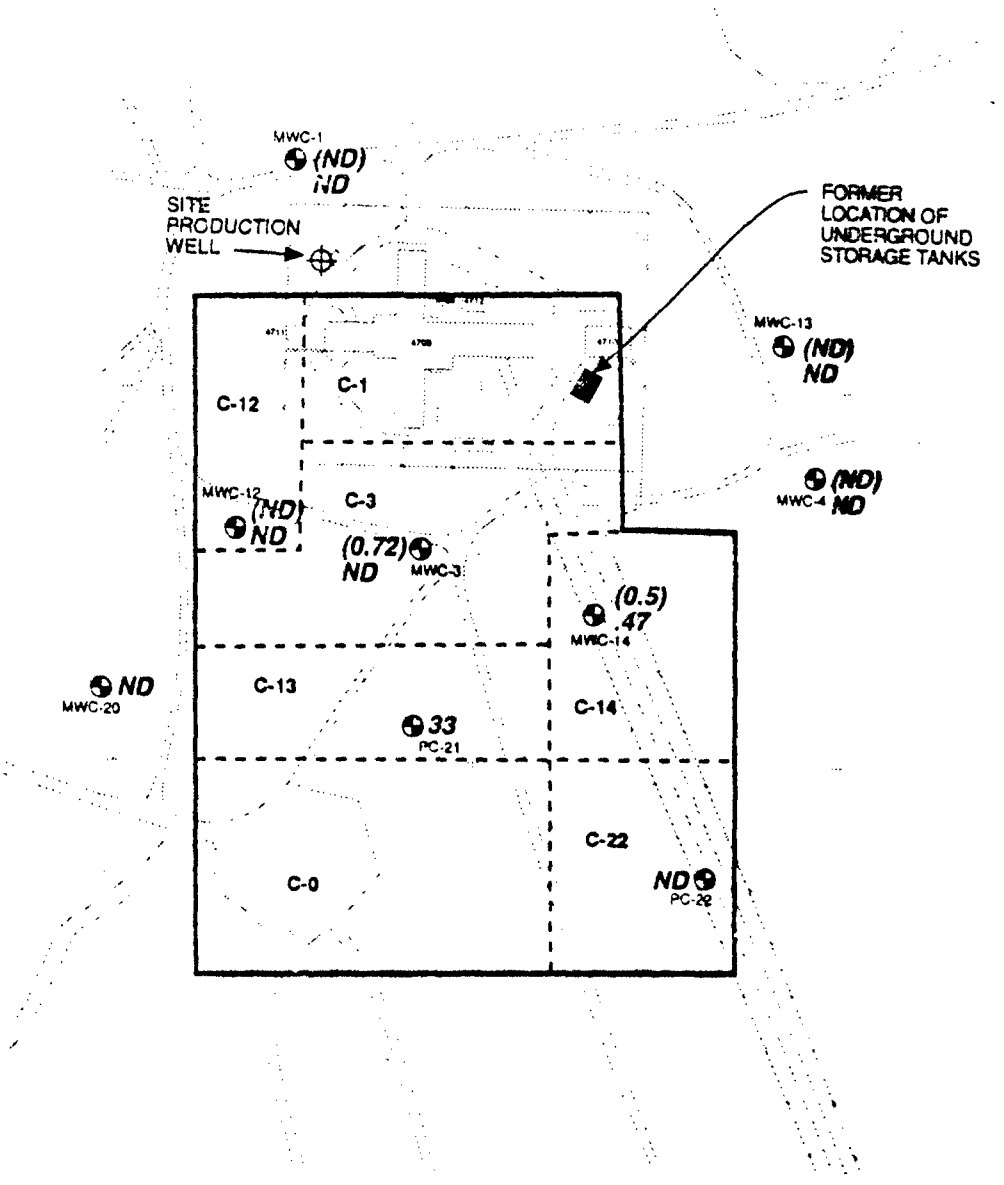
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 9
C AQUIFER POLYGON AREAS
TCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_2R8
5055 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

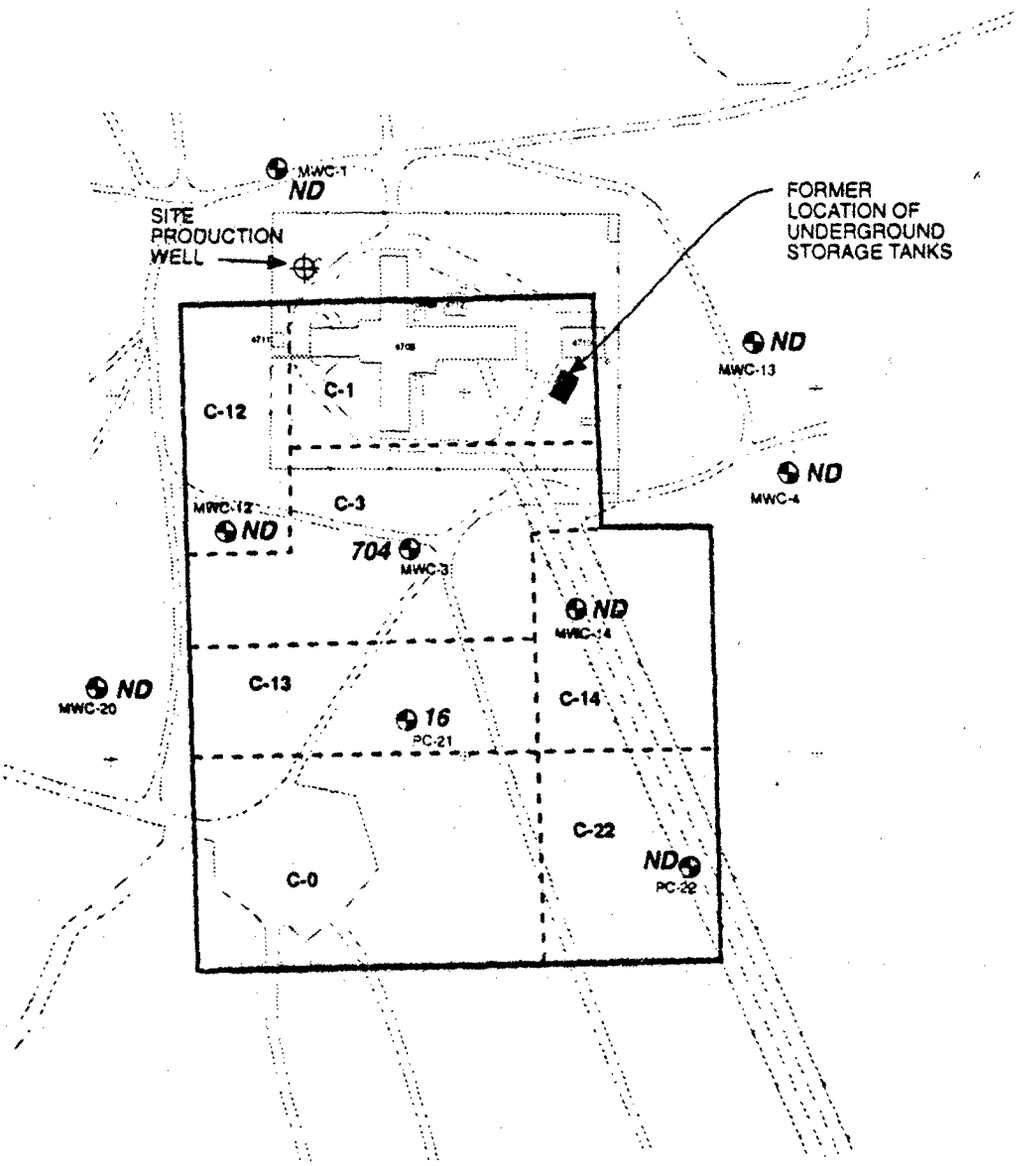
SCALE (Approximate)

0 250 FEET

FIGURE F(e) ATTACHMENT 1 page 10
C AQUIFER POLYGON AREAS
1,2-DCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

1001412_293
056 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- *1.2* CONCENTRATION IN µg/l 7/93
- *ND* NONDETECT

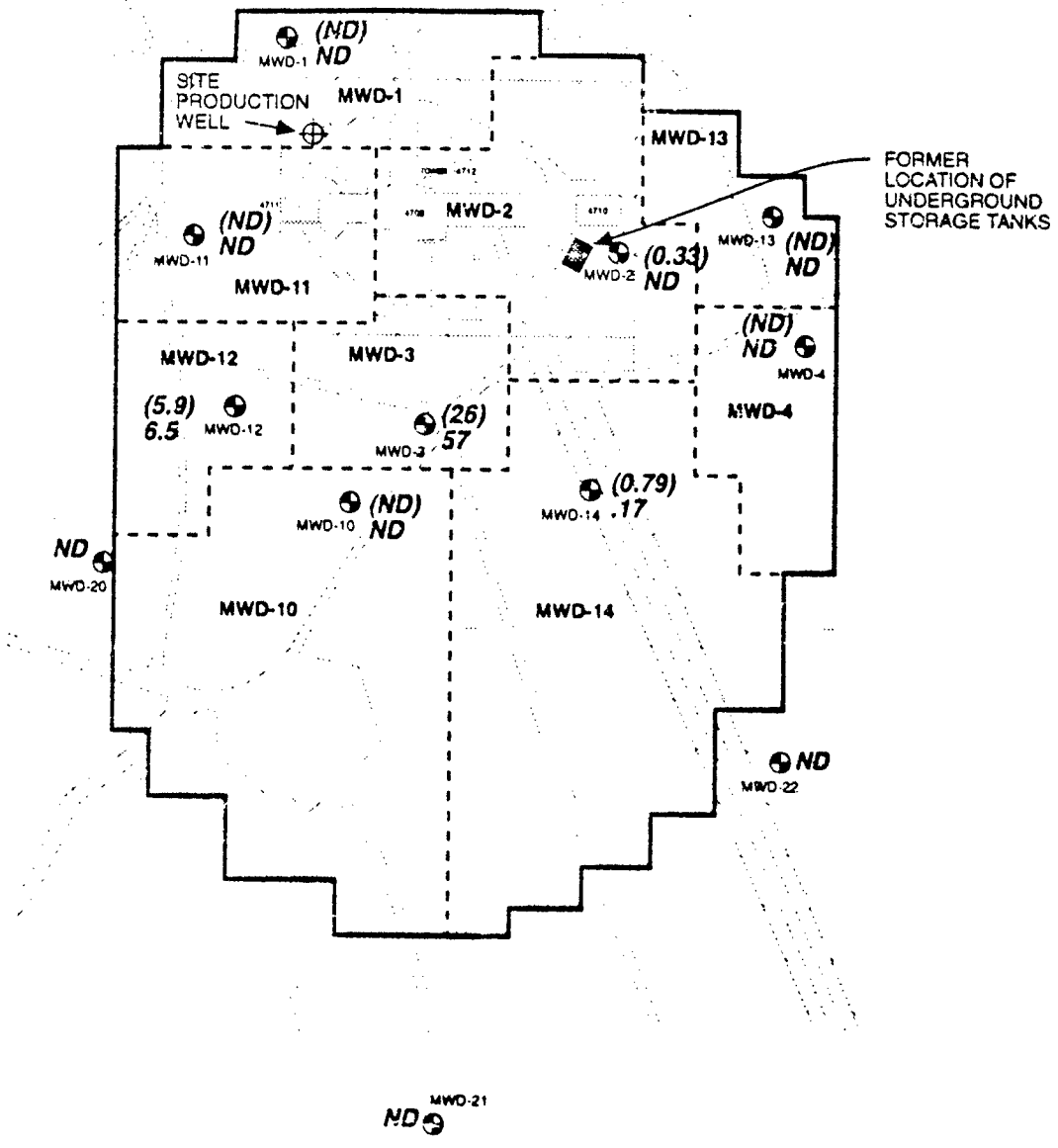
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 11
C AQUIFER POLYGON AREAS
1,1-DCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_2R8
5056 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

N

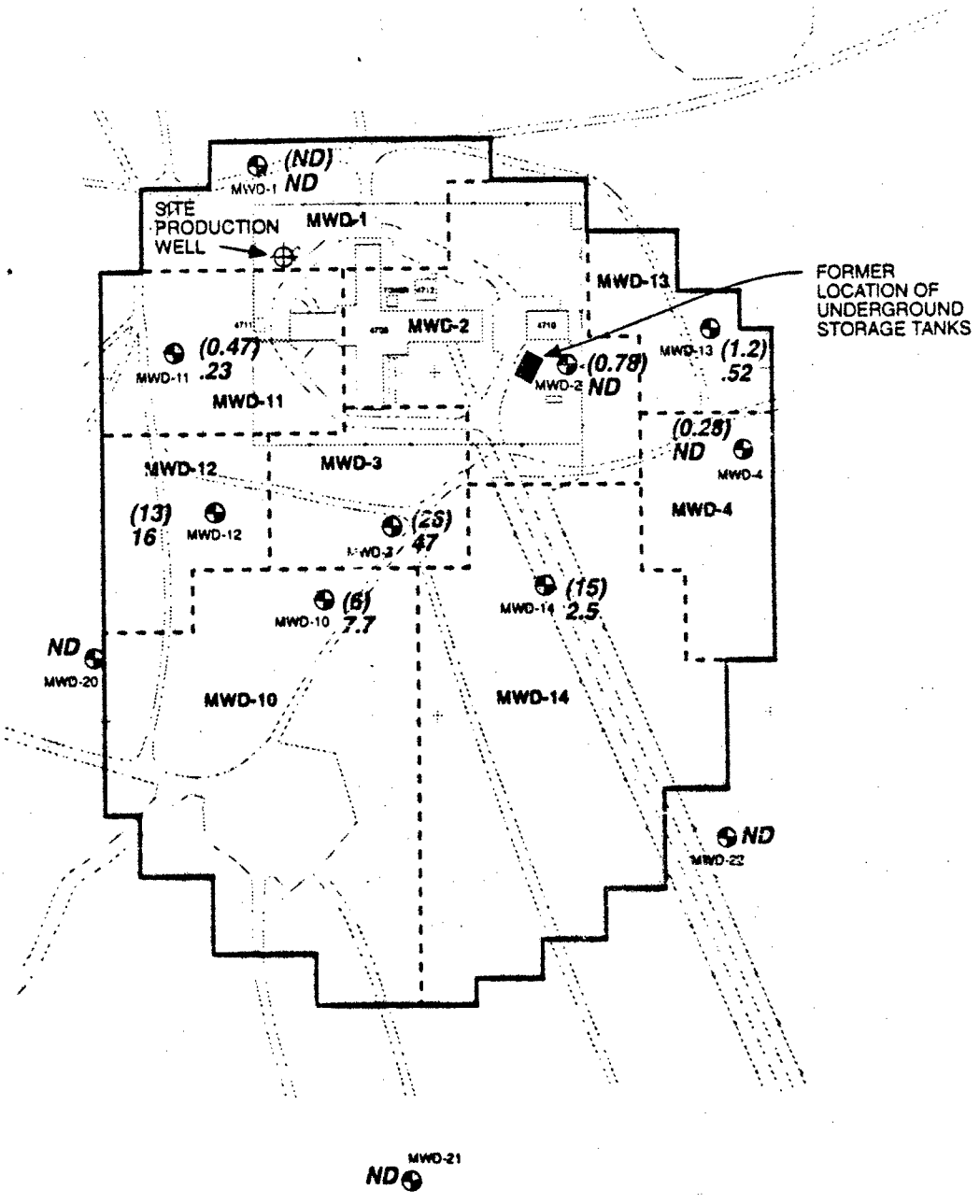
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 12
D AQUIFER POLYGON AREAS
PCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412 283
5055 19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- (1.7) 1.2 — CONCENTRATION IN µg/l (2/93), 7/93
- (ND) ND — NONDETECT (2/93), 7/93

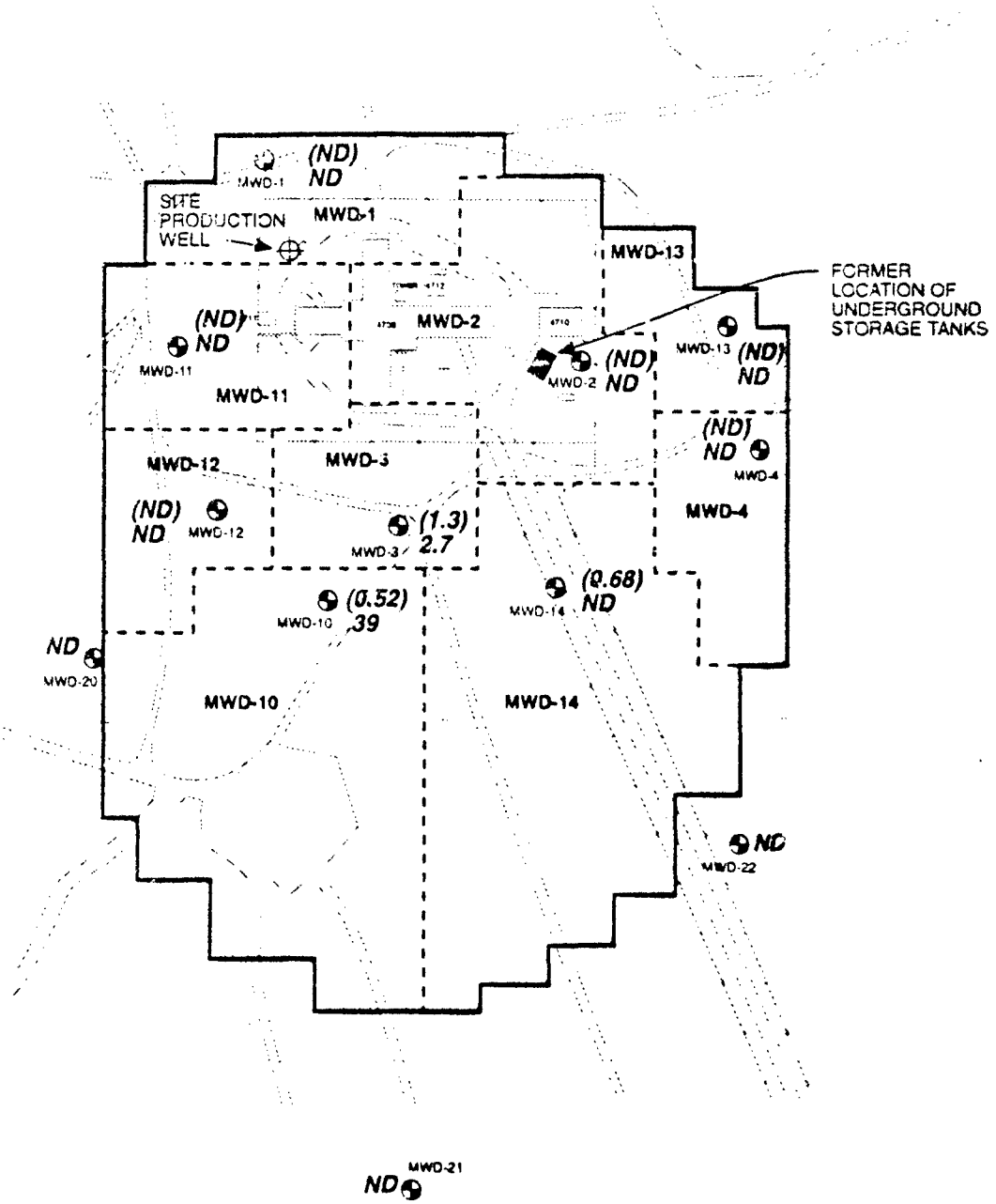
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 13
D AQUIFER POLYGON AREAS
TCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_294
5055 19

CHEMHILL



LEGEND

GROUNDWATER EXTRACTION WELL

(1.7) 1.2 CONCENTRATION IN µg/l (2/93), 7/93

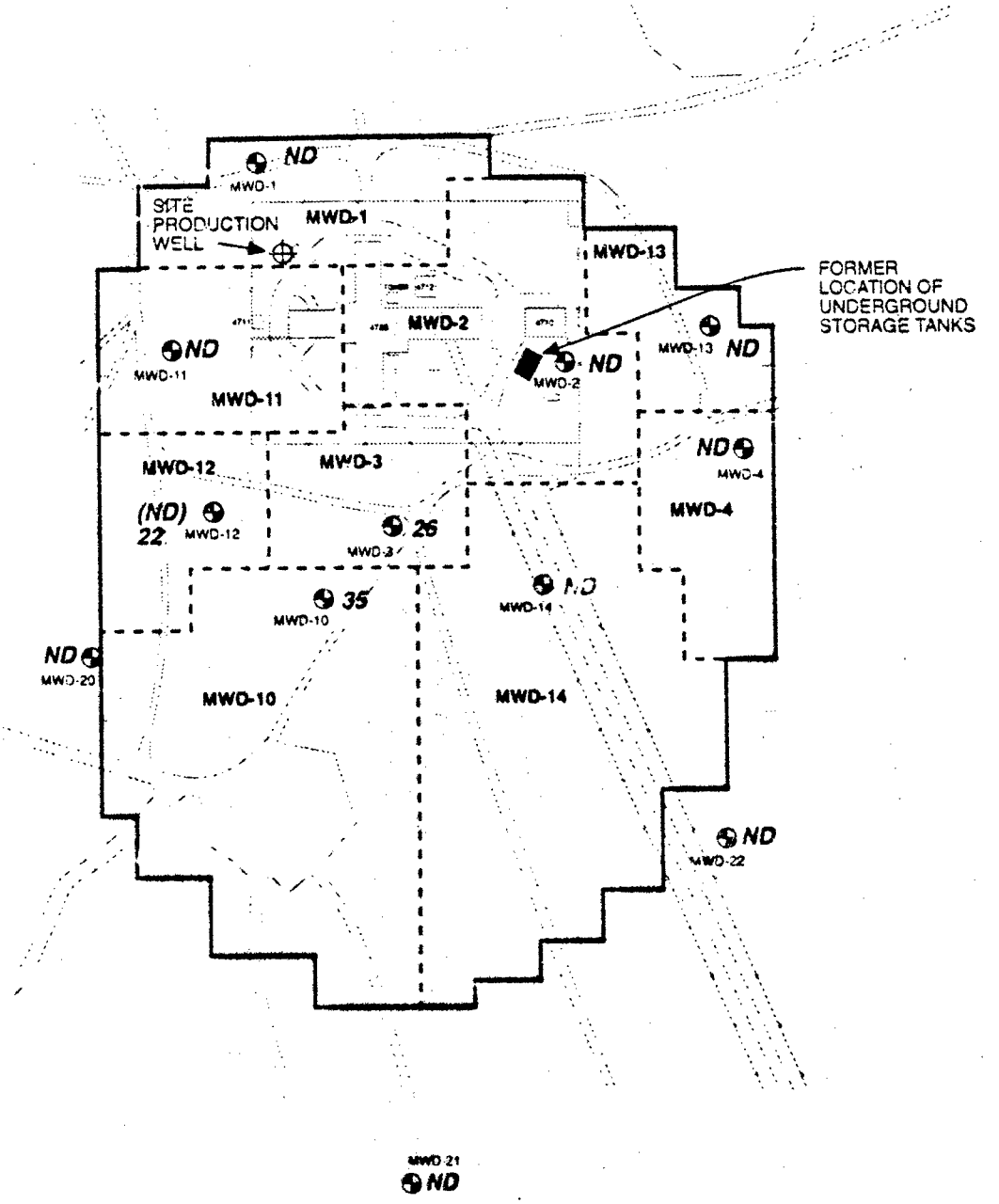
(ND) ND NONDETECT (2/93), 7/93

SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 14
D AQUIFER POLYGON AREAS
1,2 DCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2M HILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- *(1.7) 35* CONCENTRATION IN µg/l (2/93), 7/93
- *(ND) ND* NONDETECT

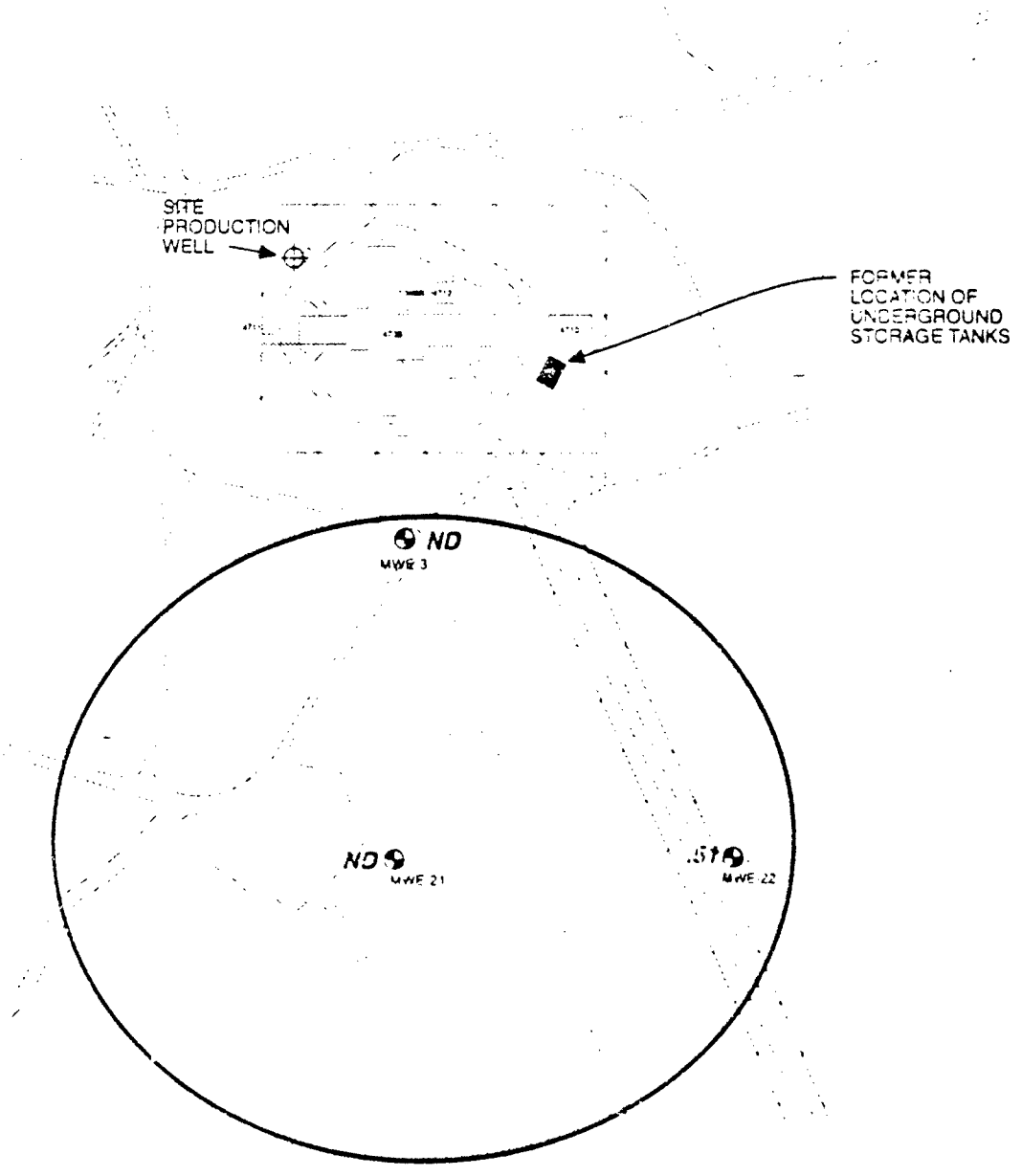
SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 15
D AQUIFER POLYGON AREAS
1,1 DCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412 2/98



LEGEND

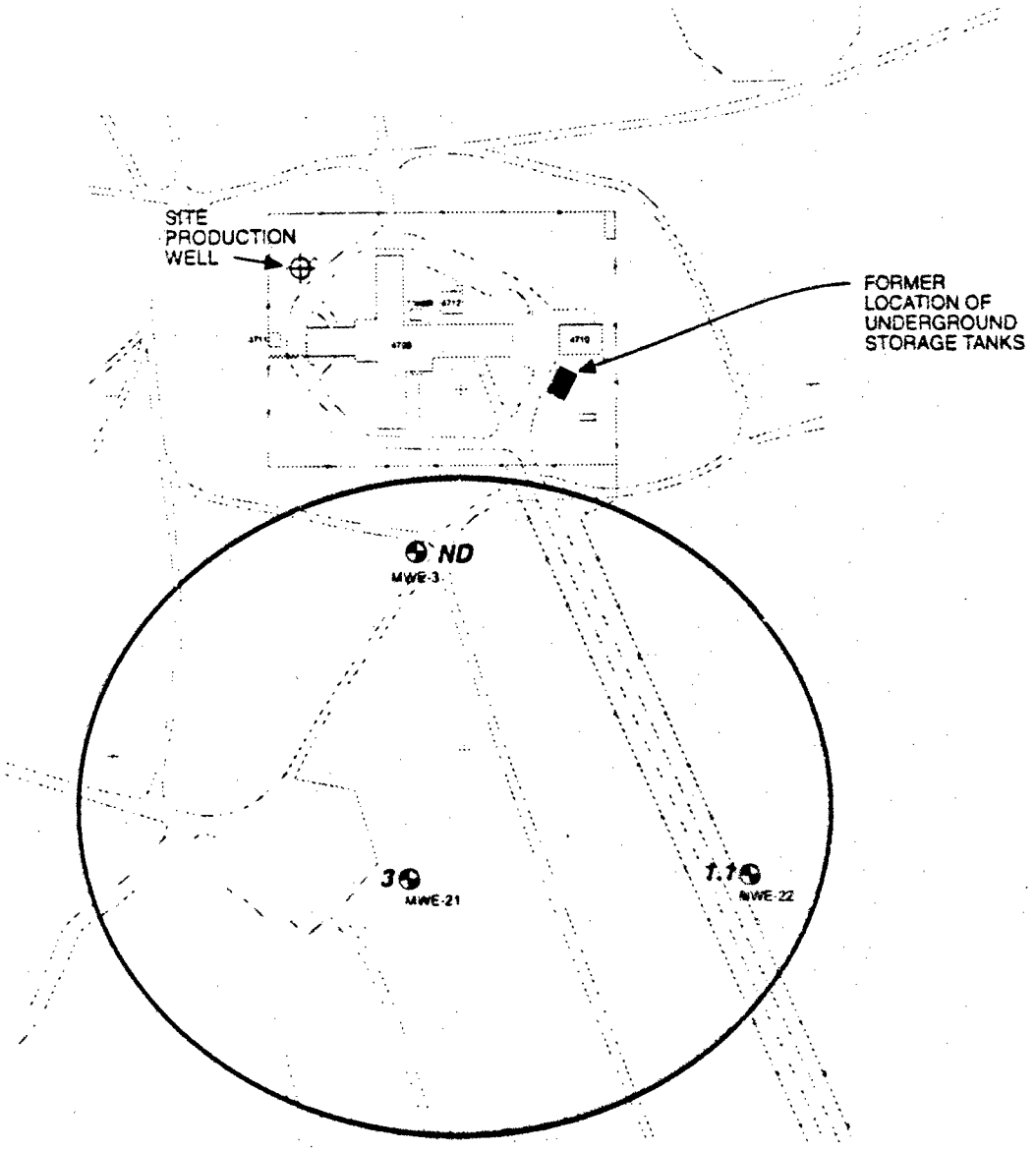
- GROUNDWATER EXTRACTION WELL
- 1.2 CONCENTRATION IN µg/l 7/93
- ND NONDETECT 7/93

SCALE (Approximate)

0 250 FEET

FIGURE F(a) ATTACHMENT 1 page 16
E AQUIFER POLYGON AREAS
PCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
MCCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL



LEGEND

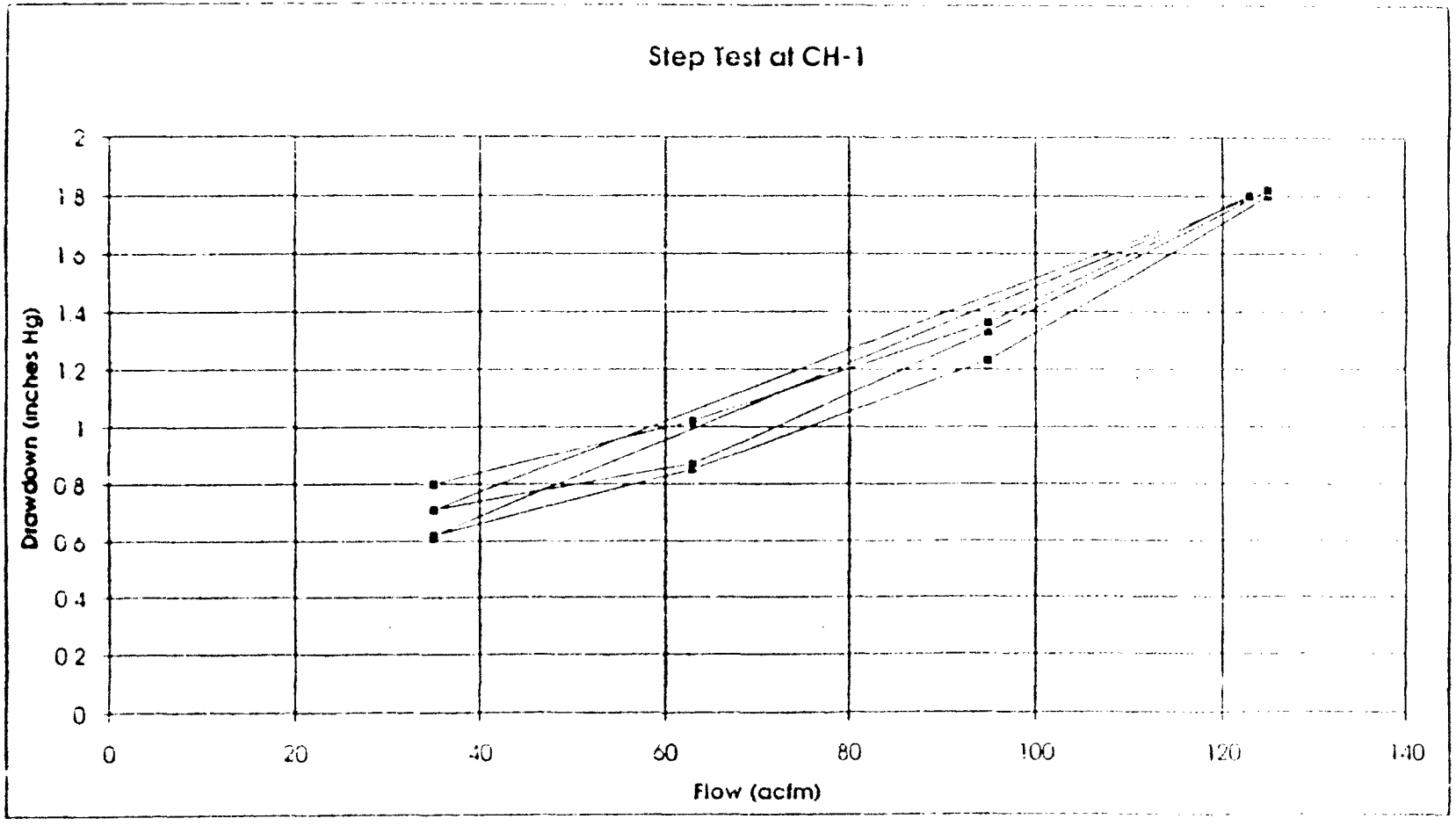
- GROUNDWATER EXTRACTION WELL
- *1.2* CONCENTRATION IN ug/l 7/93
- *ND* NONDETECT

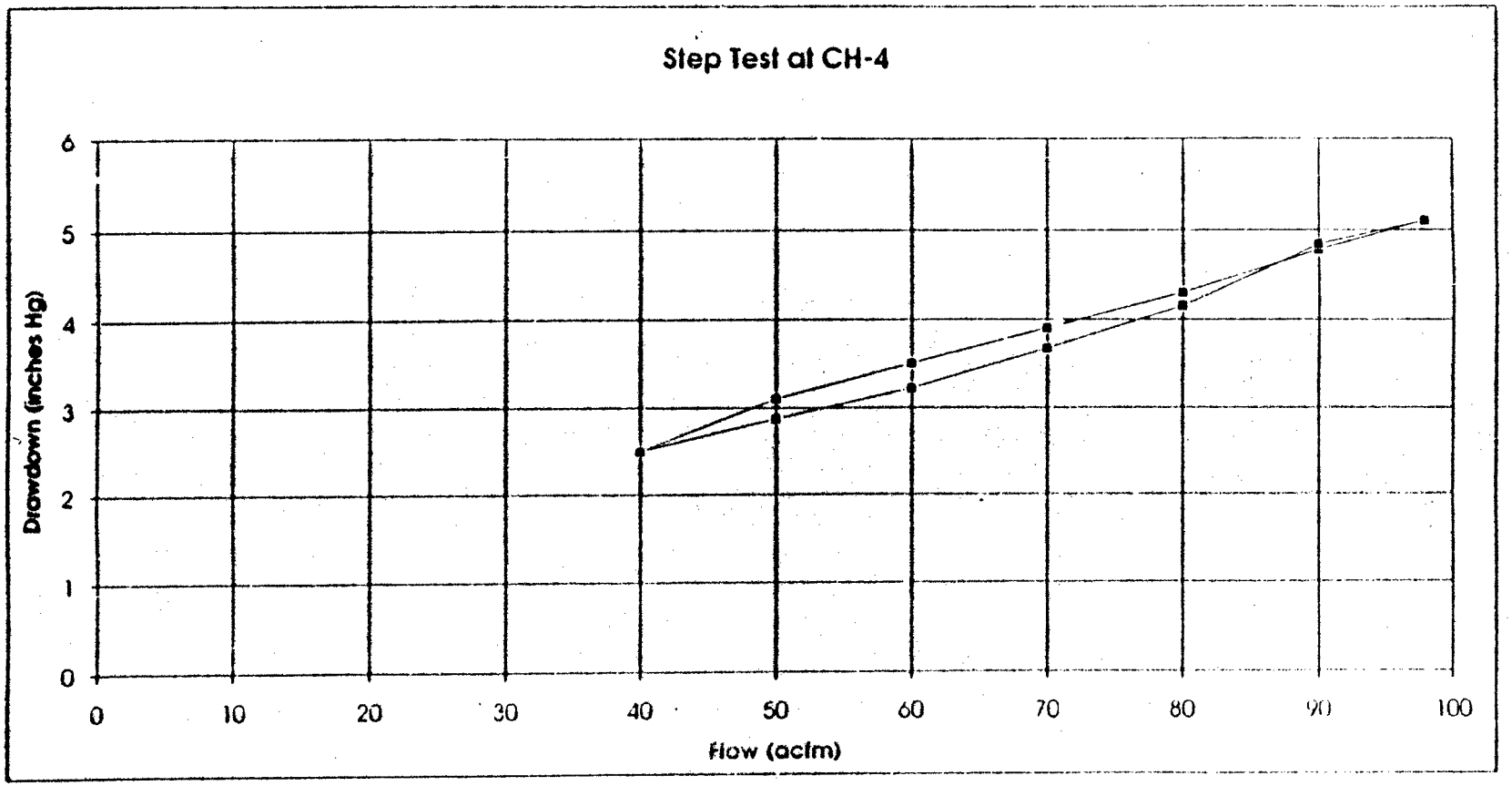
SCALE (Approximate)

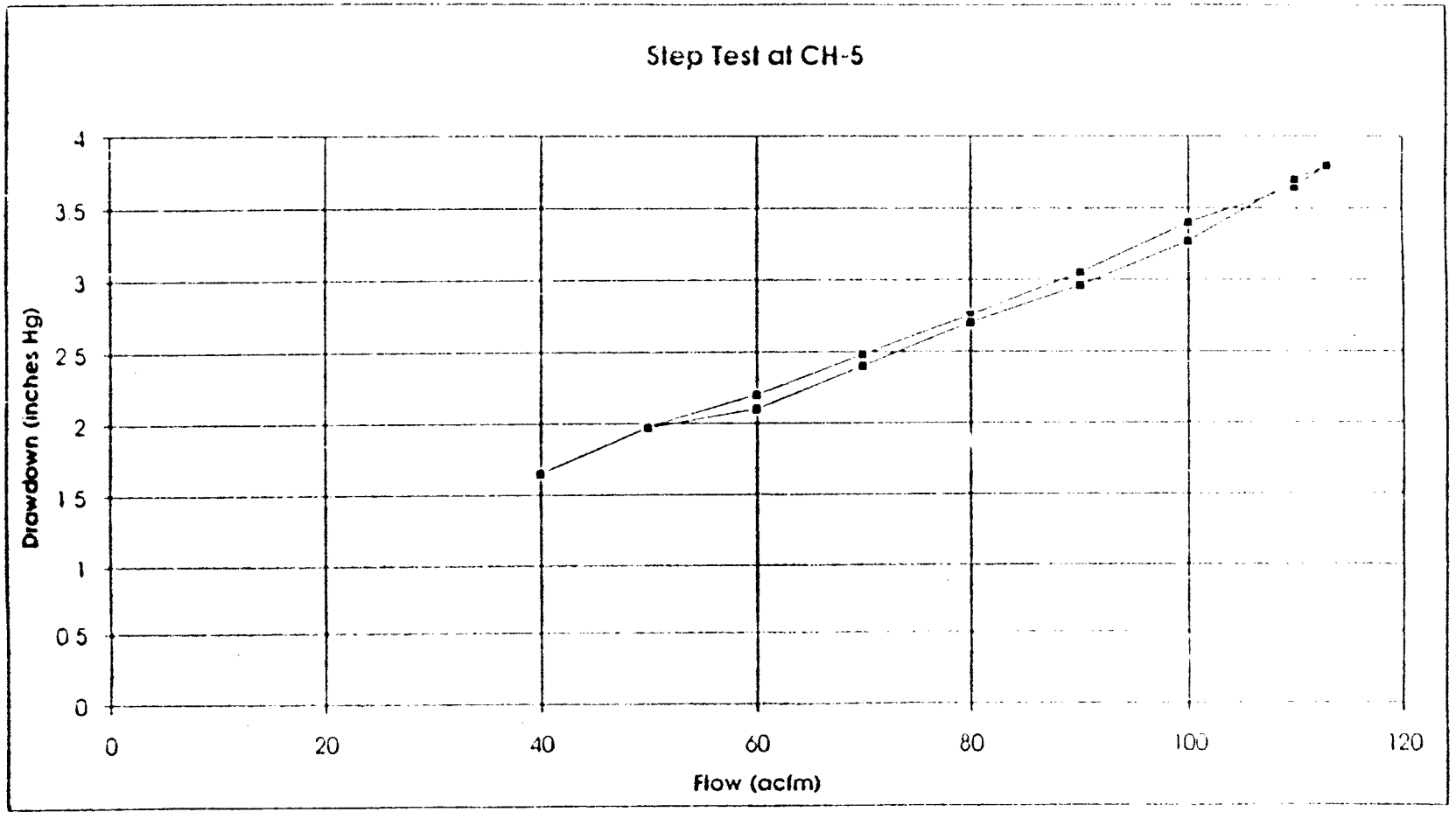
0 250 FEET

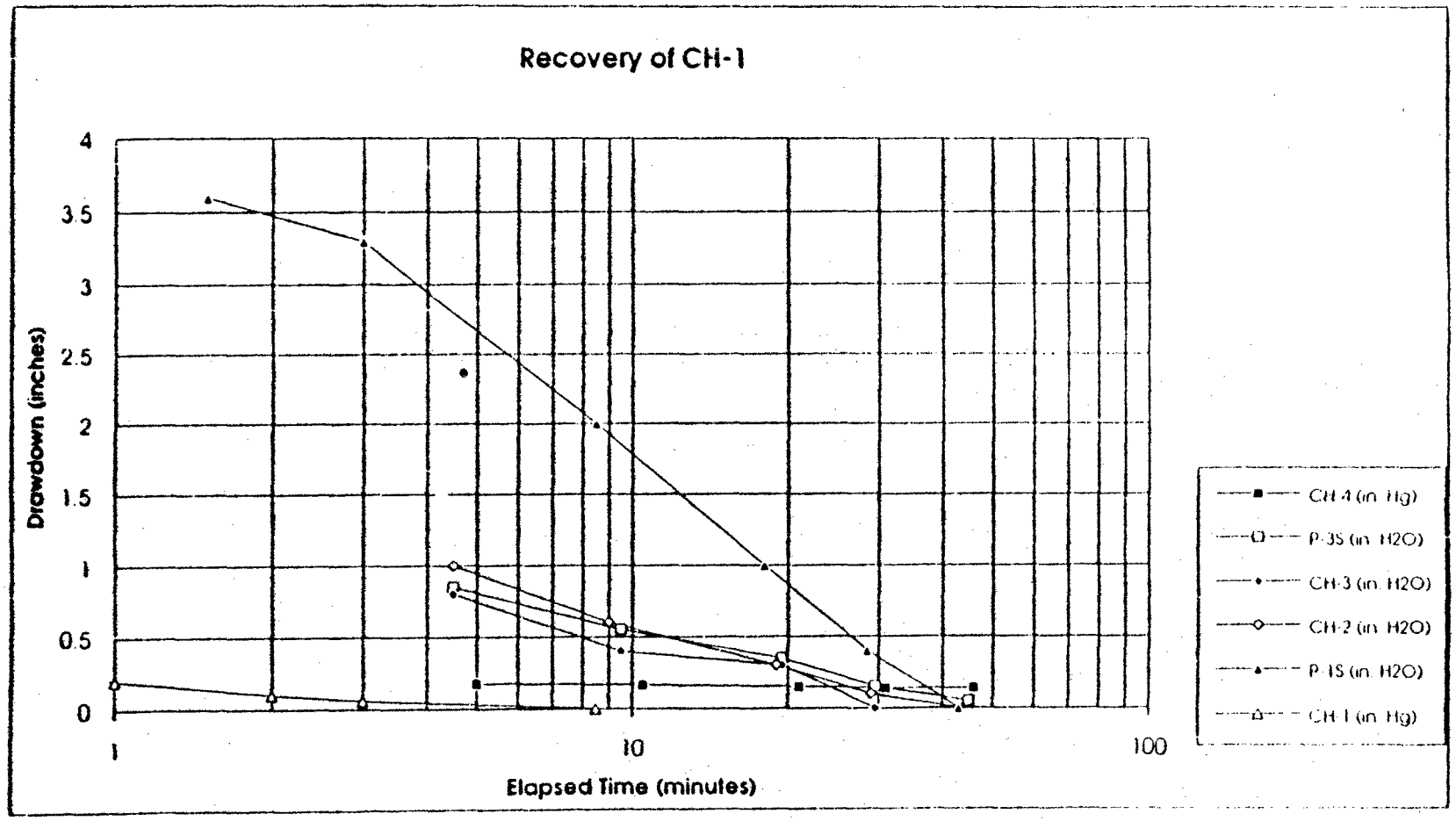
FIGURE F(a) ATTACHMENT 1 page 17
E AQUIFER POLYGON AREAS
TCE CONCENTRATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL


Step Test at CH-1
Drawdown (inches Hg)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140
Flow (acfm)


Step Test at CH-4
Drawdown (inches Hg)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100
Flow (acfm)


Step Test at CH-5
Drawdown (inches Hg)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
Flow (acfm)


Recovery of CH-1
Drawdown (inches)
4
3.5
3
2.5
2
1.5
1
0.5
0
1
10
100
Elapsed Time (minutes)
CH-4 (in. Hg)
P-3S (in. H2O)
CH-3 (in. H2O)
CH-2 (in. H2O)
P-1S (in. H2O)
CH-1 (in. Hg)

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Kathryn Morrow/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Mass Estimates for Contaminants of Concern in the Vadose Zone
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.18

Introduction

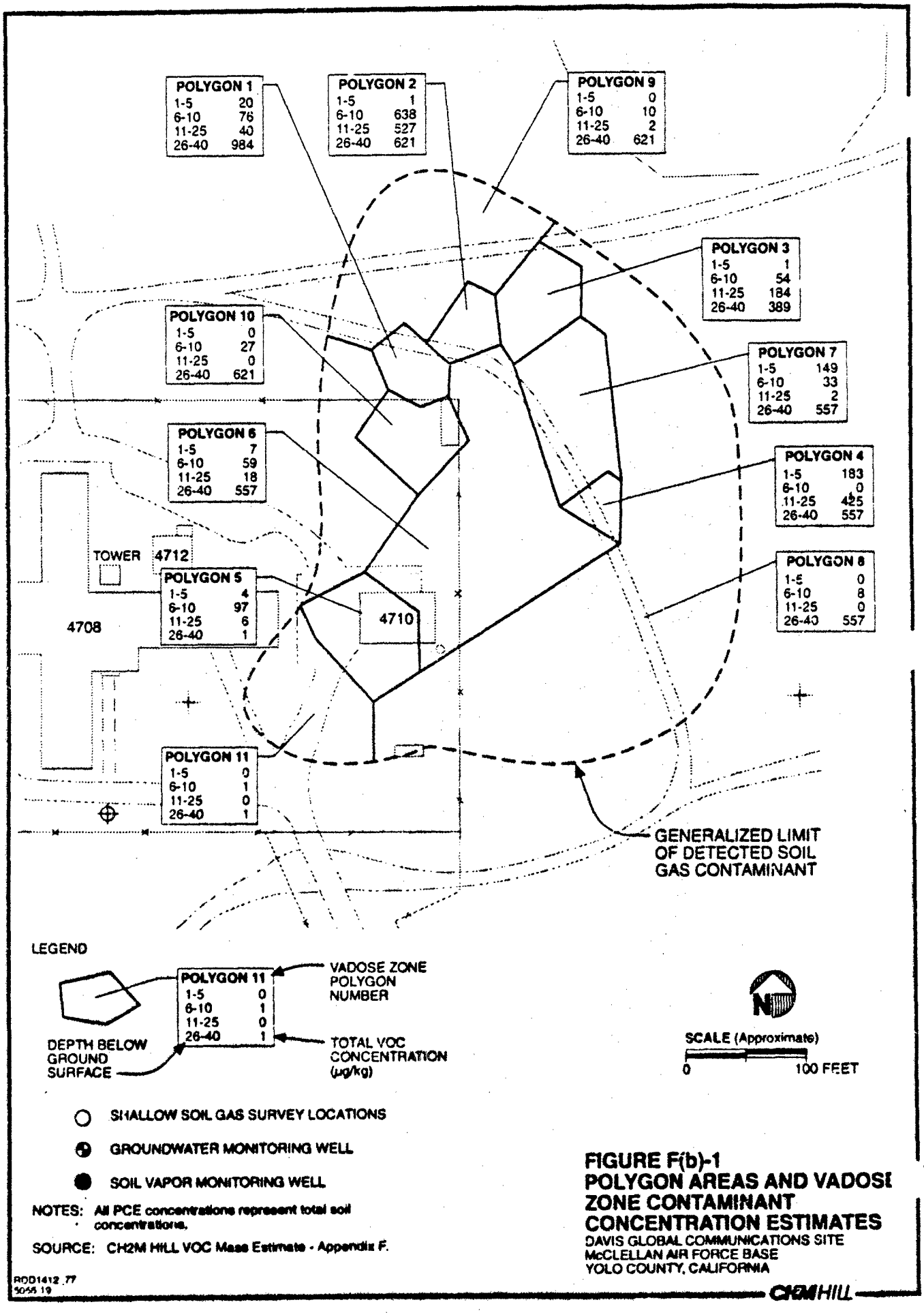
The purpose of this technical memorandum is to present the procedures used to estimate the mass of volatile organic compounds (VOCs) present in the vadose zone at the Davis Global Communications Site (Davis Site). VOCs are chlorinated organic compounds that readily volatilize into air. The presence of a significant quantity of VOCs in the vadose zone could act as a source for future groundwater contamination.

The objective of the mass estimate is to determine which contaminants are the primary contaminants of concern (COCs) and to develop a conservative estimate of the total mass of these contaminants within the vadose zone. The estimate of mass in the vadose zone will be used as input to VLEACH, a one-dimensional, finite-difference contaminant transport model. VLEACH will be used to estimate the future mass loading of VOCs to the groundwater from existing vadose zone contamination. The results of these calculations will assist in the selection of a remedial action for implementation at the site.

Figure F(b)-1 shows the site, the extent of the contamination, and the areas into which the site was divided to estimate the mass of VOCs in the vadose zone. Table F(b)-1 is a summary of the mass of contaminant found in each polygon through the entire depth.

Approach

The determination of the VOCs in the vadose zone involved a review of all available soil gas data collected at the site. These data are presented in Appendix U, Historic Contaminant Data. The data used for this analysis were collected from two sources:



NOTES: All PCE concentrations represent total soil concentrations.

SOURCE: CH2M HILL VOC Mass Estimate - Appendix F.

FIGURE F(b)-1
POLYGON AREAS AND VADOSE ZONE CONTAMINANT CONCENTRATION ESTIMATES
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RODI412.77
5055.19

- A shallow soil gas investigation in October 1992
- Sampling of five soil vapor monitoring wells (SVMWs) in December 1992

Table F(b)-1
Summary of Mass of VOCs in each Polygon

Polygon	Mass of VOCs (kg)
1	1.7
2	1.9
3	1.5
4	1.0
5	0.2
6	9.5
7	3.0
8	18.5
9	5.8
10	1.7
11	0.0
Total	**44.8**

On the basis of this data evaluation, the primary COCs were determined. A contaminant was considered to be a COC if its mass represented greater than 1 percent of the total VOC mass at a particular location. The majority of the detected contaminants were eliminated using this procedure, and the remaining contaminants are presented in Table F(b)-2. Table F(b)-2 indicates the majority of the vadose zone contamination at the site consists of tetrachloroethene (PCE).

As PCE and trichloroethene (TCE) account for approximately 94 percent of the total mass of contamination, the combined value of these contaminants was considered sufficient to obtain an estimate of the total mass of VOCs in the vadose zone. For the calculations presented here, the vadose zone is considered to extend to 40 feet below ground surface (bgs).

The depth intervals were determined by the sample location depths. The shallow soil gas samples were usually taken at 5, 10, and 20 feet bgs, and the screened interval in the SVMWs extended from 25 to 38 feet bgs. Soil gas samples were also collected from the piezometers associated with each SVMW.

Table F(b)-2 VOC Mass at Depth in the Vadose Zone (μg/kg)						
VOCs	Depth (feet bgs)				Total Mass of VOC	% of Total Mass
	0 to 5	6 to 10	11 to 25	26 to 40		
PCE	338.6	991.8	144.0	2,483.6	5,254	90.1
TCE	25.4	14.42	90.7	114.4	244.9	4.2
1,1-DCE	0.8	0.9	6.8	11	19.5	0.3
Benzene	0.4	2.9	0.6	2.1	6.0	0.1
Toluene	1.9	19.7	94.8	0.6	117	2.0
0-xylene	0.8	41.4	0.4	0.0	42.6	0.7
m,p-xylene	6.9	138.6	4.1	0.0	149.6	2.6
Vinyl Chloride	0.0	0.0	0.0	.1	0.1	
Total VOC Mass in Zone	374.8	1,209.72	1,637.4	2,611.8	5,833.7	
Percent of Total in Zone	6.4	20.7	28.1	44.8		

Mass Estimate Evaluation

The area in which the mass estimate was performed was delineated using the available data to outline the known extent of the soil vapor plume. The total area was then subdivided into areas of similar contaminant concentrations, termed polygons. The areas around the SVMWs were contained in smaller polygons as these were areas of more intensive sampling. The area that did not fall within the polygons established around the SVMWs was divided based on similar total VOC concentrations. The site and the corresponding polygons are shown in Figure F(b)-1.

For Polygons 6 through 11, only shallow soil gas data were available. To compensate for the lack of data in the lower zones of these polygons, the VOC concentration found in the nearest SVMW was extrapolated into the adjacent polygon. This procedure is considered to provide a conservatively high estimate of the VOC mass in these polygons as the SVMWs were established in areas of high VOC contamination, based on shallow soil gas and soil borehole sampling results.

The procedure used to calculate the estimated mass of total VOCs was as follows (HydroGeoChem, Inc., 1989):

Soil Volume

- Estimate the extent of contamination
- Subdivide the area into areas (termed polygons) of similar contaminant concentrations
- Determine the surface area of each polygon using a planimeter
- Determine the depth zones beneath the polygons based on lithology of the layers and the distribution of the contaminant
- Determine the volume of soil in each zone
- Convert volume of soil to mass using an estimate of soil bulk density

Contaminant Concentration

- Review VOC data base
- Determine contaminants of concern
- Sort contaminants based on areas and depths established above
- Convert soil gas concentrations into total soil concentrations based on the following equations:

$$K_{gt} = [K_{ws} * \rho_b + \theta_w)/K_h + (\theta_t - \theta_w)]/\rho_b$$

K_{ws} was calculated using the following equation:

$$K_{ws} = (K_{oc} * f_{oc})$$

All variables are defined in Table F(b)-3.

Table F(b)-3 Equation Variable Definitions		
K_{gt}	=	Conversion factor used to convert soil gas concentrations ($\mu g/l$) to total soil concentrations ($cm^3/\mu g$ soil)
K_{ws}	=	Water-solid distribution coefficient (cm^3 water/μg soil)
K_h	=	Henry's Law Constant $\left(\frac{cm^3 \text{ water}}{cm^3 \text{ air}}\right)$
K_{oc}	=	Water-organic carbon distribution coefficient $\left(\frac{cm^3 \text{ water}}{\mu g \text{ soil}}\right)$
C_g	=	Soil gas concentration $\left(\frac{\mu g \text{ contaminant}}{cm^3 \text{ air}}\right)$
C_t	=	Total soil concentration $\left(\frac{\mu g \text{ contaminant}}{kg \text{ soil}}\right)$

K_h and K_{oc} are established parameters for each contaminant and are presented in Table F(b)-4.

Table F(b)-4 Assumed Chemical Properties for COCs		
VOC	K_{oc} (cm^3/g)	K_h (dimensionless)
PCE	364	0.545
TCE	126	0.30
1,1-DCE	65	0.87
Benzene	91	0.224
Toluene	151	0.28
0-Xylene	129	0.22
m,p-Xylene	1580	0.3
Vinyl Chloride	2.5	116
Source: Scheville, F. 1988. *Dense Chlorinated Solvents.* Lewis Publishers.		

The total soil concentration (C_t µg/kg) was determined using:

$$C_t = C_g * K_{gt}$$

The parameters assumed as constant for the calculations are presented in Table F(b)-5.

Table F(b)-5
Assumed Soil Properties

Bulk Density – p_b (gr/cm^3)	1.45
Total Porosity – θt (%)	40
Water-filled Porosity – θw (%)	20
Fraction of Organic Carbon – f_{oc}	0.0022

The total soil concentrations of each contaminant in the volumes previously established were summed to find the concentration of total VOCs.

The concentrations were used to determine the approximate total VOC mass in each depth zone within a polygon.

Attachment F(b)-1 is an example of the procedure used to obtain the mass estimate.

Results and Conclusions

The results obtained from the estimate of the mass of VOCs in the vadose zone indicate that the contamination primarily consists of PCE (90.1 percent) and 45 percent of the total mass resides between 26 through 40 feet bgs. As indicated in Table F(b)-1, the greatest mass of contaminant resides in Polygon 8. This value is conservative as the data from the adjacent soil vapor monitoring at a depth of 26 through 40 feet bgs were extrapolated to the much larger polygon area. The extent of the contamination, indicated in Figure F(b)-1, is based on the results of the shallow soil gas survey.

Table F(b)-6 presents the data for each polygon area used in estimating the mass of VOCs in the vadose zone. In the case where 0's are present, the sample results indicated nondetectable levels of VOCs in the depth interval. In the cases where data were not available, data from the SVMWs were extended to surrounding polygon areas, as described previously.

Table F(b)-6
Mass Estimates for the Vadose Zone (0 to 40 ft bgs)

Polygon No.	Area (ft^2)	Soil Depth Interval (ft bgs)	Soil Volume (ft^3)	Mass of Soil (kg)	Total VOC Concentration (µg/kg)	Mass of VOCs (gr)	Mass of VOCs (kg)	Mass of VOCs (lb)
1	2,600	0-5	13,000	534,000	20.46	10.93	0.01	0.02
		6-10	13,000	534,000	76.36	40.78	0.04	0.09
		11-25	39,000	1,603,000	40.29	64.58	0.06	0.14
		26-40	39,000	1,603,000	983.77	1,576.98	1.58	3.47
2	2,200	0-5	11,000	452,000	0.48	0.22	0.00	0.00
		6-10	11,000	452,000	638.31	288.52	0.29	0.64
		11-25	33,000	1,356,000	526.99	714.60	0.71	1.57
		26-40	33,000	1,356,000	621.30	842.48	0.84	1.86
3	4,200	0-5	21,000	863,000	0.41	0.35	0.00	0.00
		6-10	21,000	863,000	53.95	46.56	0.05	0.10
		11-25	63,000	2,589,000	184.34	477.26	0.48	1.05
		26-40	63,000	2,589,000	389.24	1,007.74	1.01	2.22
4	1,500	0-5	7,500	308,000	183.04	56.38	0.06	0.12
		6-10	7,500	308,000	0.00	0.00	0.00	0.00
		11-25	22,500	925,000	425.33	393.43	0.39	0.87
		26-40	22,500	925,000	557.13	515.35*	0.52	1.13
5	6,100	0-5	30,500	1,253,000	3.80	4.76	0.00	0.01
		6-10	30,500	1,253,000	96.97	121.50	0.12	0.27
		11-25	91,500	3,760,000	6.02	22.64	0.02	0.05
		26-40	91,500	3,760,000	1.21	4.55	0.00	0.01
6	25,800	0-5	129,000	5,301,000	6.51	34.51	0.03	0.08
		6-10	129,000	5,301,000	58.61	310.69	0.31	0.68
		11-25	387,000	15,902,000	18.19	289.26	0.29	0.64
		26-40	387,000	15,902,000	557.10	8,859.00	8.86	19.5
7	7,900	0-5	39,500	1,623,000	149.34	242.38	0.24	0.53
		6-10	39,500	1,623,000	32.56	52.84	0.05	0.12
		11-25	118,500	4,869,000	0.00	0.00	0.00	0.00
		26-40	118,500	4,869,000	557.10	2,712.52	2.71	5.97
8	53,500	0-5	267,500	10,992,000	0.00	0.00	0.00	0.00
		6-10	267,500	10,992,000	8.29	91.12	0.09	0.20
		11-25	802,500	32,976,000	0.00	0.00	0.00	0.00
		26-40	802,500	32,976,000	557.10	18,370.93	18.37	40.5
9	15,000	0-5	75,000	3,082,000	0.00	0.00	0.00	0.00
		6-10	75,000	3,082,000	9.53	29.37	0.03	0.06
		11-25	225,000	9,245,000	1.80	16.64	0.02	0.04
		26-40	225,000	9,245,000	621.30	5,743.92	5.74	12.6
10	4,300	0-5	21,500	883,000	0.00	0.00	0.00	0.00
		6-10	21,500	883,000	26.98	23.82	0.02	0.05
		11-25	64,500	2,650,000	0.00	0.00	0.00	0.00
		26-40	64,500	2,650,000	621.30	1,646.45	1.65	3.63
11	8,100	0-5	40,500	1,664,000	0.00	0.00	0.00	0.00
		6-10	40,500	1,664,000	0.69	1.15	0.00	0.00
		11-25	121,500	4,993,000	0.00	0.00	0.00	0.00
		26-40	121,500	4,993,000	1.21	6.04	0.01	0.01
Totals	**131,200**			**215,646,000**	**8,037.01**	**44,620.25**	**44.62**	**98.3**

Some uncertainties encountered during the calculations were generated from limited soil properties data. The f_{oc} value was based on the average of four samples collected during the installation of soil vapor monitoring wells. One bulk density was estimated for the area, through the depth of the polygon areas so changes in the stratigraphy were not accounted for. A constant total porosity and water-filled porosity were assumed for all calculations. The sensitivity of the data to these parameters was evaluated, and the f_{oc} value was the only parameter that appeared to cause any significant variation in the mass of VOCs. Table F(b)-7 presents data based on three f_{oc} values.

Table F(b)-7
Sensitivity Analysis for f_{oc} on Mass Estimates on Polygon No. 1

Depth Interval (feet)	Mass of Contaminant (grams)		
	f_{oc} = 0.001	f_{oc} = 0.0022	f_{oc} = 0.003
0 to 5	6.3	11.1	14.2
6 to 10	23.4	41.2	53.1
11 to 25	74.7	130	167.7
26 to 40	910.3	1,620.3	2,093.1

The f_{oc} value used was based on sample results and is considered a fair representation of actual f_{oc} values at the site.

A low Henry's Law constant was used in the calculation of contaminant concentrations in the sorbed and aqueous phases based on soil gas concentrations. As the value of the Henry's Law constant increases the greater the mass of contaminant existing in the vapor phase. The lower value provided a more conservatively high estimate of mass of the contamination.

Works Cited

HydroGeoChem, Inc. 1989. *Revised Estimate of Volatile Organic Contaminant Mass at the Phoenix–Goodyear Airport Superfund Site, Goodyear, Arizona.* July.

Scheville, F. 1988. *Dense Chlorinated Solvents.* Lewis Publishers.

Attachment F(b)-1

CH2MHILL SUBJECT DAVIS-GLOBAL COMM BY _____ DATE 7/16
VADOSE ZONE VOC. MASS ESTIMATES PROJECT NO. 28722.55.13 SHT 1 OF 2

EXAMPLE OF MASS CALCULATION FOR POLYGON #1 FROM 11-25 ft bgs

AREA OF POLYGON 1 = 2628.8 ft (from planimeter)
Δ DEPTH = 15 ft

VOLUME = 15 x 2628.8 = 39,432 ft^3

CONVERT VOL. TO MASS:

$$39432\ ft^3 \times \frac{1\ m^3}{3.28^3\ ft^3} \cdot \frac{100^3\ cm^3}{m^3} \cdot \frac{1.45\ g}{cm^3} \times \frac{1\ kg}{1000\ g} =$$

$$= 1,620,299.\ kg\ OF\ SOIL$$

THE CONCENTRATIONS OF PCE + TCE ARE USED FOR SOIL GAS AS THEY COMPRISE 95% OF THE TOTAL VOCs (SHOWN IN TABLE 1).

Conc. TCE = 0.217
Conc. PCE = 21.58
} from CH-1, SG09

CONVERT TCE (ug/L) TO TCE (ug/kg)

FOR TCE - $K_h = 0.30$

$K_{oc} = 126\ cm^3/g$

$Conc_{TOTAL} = Conc._{SG} \cdot K_{gT}$

where $K_{gt} = [(K_{ws} \rho_b + \theta_w) / K_h + (\theta_T - \theta_w)] / \rho_p$

$\rho_b = 1.45\ g/cm^3$
$\theta_w = 0.2$
$\theta_T = 0.4$
$K_{ws} = (K_{oc} \cdot f_{OC}^{(\%)}) / 100$

$K_{ws} = (126 \cdot .22)/100 = 0.2772$

$K_{ST} = \{(0.2772 \cdot 1.45 + 0.2)/0.3 + (0.4 - 0.2)\}/1.45$

$K_{ST} = 1.52$

$C_T = 1.52(0.217) = 0.33 \text{ ug/kg}$

SIMILARLY, FOR PCE:

$K_h = 0.545$
$K_{oc} = 364$
$K_{ws} = 0.801$

$K_{ST} = 1.86$

$C_T = (1.86)(21.58.) = 40.14 \text{ ug/kg}$

FOR TOTAL VOC - ADD TCE + PCE

THE APPROXIMATE MASS OF VOCs IN POLYGON 1 BETWEEN 11-25 ft:

$40.14 + 0.33 = 40.5 \text{ ug/kg}$

$40.5 \text{ ug/kg} \cdot (1620299) = 65.6 \times 10^6$

TOTAL MASS OF VOCs IN POLYGON 1 BETWEEN 11-25 ft = 65.6 grams.
= 0.144 lbs

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Pam Bates/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: ARARs Analysis
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.13

Purpose

This technical memorandum identifies potential Applicable or Relevant and Appropriate Requirements (ARARs) and other to-be-considered (TBC) criteria for the remedial action alternatives presented in this Remedial Investigation/Feasibility Study (RI/FS) for the Davis Global Communications Site (Davis Site). Section 121(d) of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 USC §9621(d), requires that response actions conducted under CERCLA attain a level or standard of control of hazardous substances which complies with applicable or relevant and appropriate requirements of federal environmental laws and more stringent state environmental and facility siting laws.

Description of ARARs

Below is a discussion of the Federal and State statutes and regulations that have been initially identified as ARARs. This discussion is not intended to serve as the final determination of all ARARs for the Davis remedial action(s). This identification of ARARs is an iterative process throughout the RI/FS, and the final determination of ARARs will be made by the California Environmental Protection Agency (Cal/EPA) and identified in the Remedial Action Plan/Record of Decision (RAP/ROD) for the Davis Site.

ARARs include "applicable" and "relevant and appropriate" requirements. In addition to these promulgated standards, Cal/EPA may also use guidance advisories as matters "to be considered." Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site.

Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that, while not specifically "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

CERCLA provides that State requirements may be used as ARARs for Superfund sites. To be considered an ARAR, the State requirement must be promulgated, it must be more stringent than Federal requirements, and the State must identify the ARAR in a timely manner. The State ARARs discussed in this technical memorandum are based in part from the ARARs that were solicited and received from various agencies. The agencies that provided ARARs include the Department of Health Services (Office of Drinking Water), the Department of Toxic Substances Control, the Regional Water Quality Control Board (Central Valley Region), the Yolo-Solano Air Quality Management District, the Department of Fish and Game, and the County of Yolo Department of Public Health.

In addition to legally binding laws and regulations, many federal and state environmental and public health programs also develop criteria, advisories, guidance, and proposed standards that are not legally binding but that may provide useful information or recommended procedures. These materials are evaluated, along with ARARs, as part of the risk assessment conducted for each CERCLA site to establish protective cleanup level targets and to help identify remedial action alternatives.

After completion of the risk assessment, if no ARARs address a particular situation, or if existing ARARs do not ensure protectiveness, TBC advisories, criteria, or guidelines may be used to set cleanup targets. TBC values may have to be adjusted to be applied in the risk assessment. For instance, TBC values expressed as dosages may have to be converted to ambient concentration levels before they can be applied to a site.

Section 121(e) of CERCLA states that no federal, state, or local permit is required for remedial actions conducted entirely onsite. Therefore, actions conducted entirely onsite must meet only the substantive and not the administrative requirements of the ARARs. Actions that take place offsite are subject to the full requirements of federal, state, and local regulations.

ARARs can be divided into three categories:

- Chemical-specific ARARs
- Location-specific ARARs
- Action-specific ARARs

Chemical-specific ARARs include those laws and requirements which regulate the release to the environment of materials possessing certain chemical or physical

characteristics or containing specified chemical compounds. These requirements generally set health- or risk-based concentration limits or discharge limitations for specific hazardous substances. If, in a specific situation, a chemical is subject to more than one discharge or exposure limit, the more stringent of the requirements should generally be applied. The chemical compounds examined in this document are those that have been detected at the Davis Site above background concentrations in the soil, soil gas and groundwater.

Location-specific ARARs are those requirements that relate to the geographical or physical position of the site rather than the nature of the contaminants or the proposed site remedial actions. These requirements may limit the type of remedial actions that can be implemented and may impose additional constraints on the cleanup action.

Action-specific ARARs are requirements that define acceptable treatment and disposal procedures for hazardous substances. These ARARs generally set performance, design, or other similar action-specific controls or restrictions on particular kinds of activities related to management of hazardous substances. These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy. Since there are usually several alternative actions for any remedial site, very different requirements can come into play. The action-specific requirements do not in themselves determine the remedial alternative; rather, they indicate how a selected alternative must be achieved.

Chemical-Specific ARARs and TBCs

Tables G-1, G-2, and G-3 present potential chemical-specific ARARs for volatile organic compounds (VOCs), semivolatile organic compounds and pesticides, and metals in water, respectively, arranged by chemical compound. The major regulations which contribute to the list of potential chemical-specific ARARs are the Safe Drinking Water Act (SDWA) and California Department of Health Services (DHS) State Maximum Contaminant Levels (MCLs). The TBC chemical-specific materials compiled for the Davis Site consider (1) Maximum Contaminant Level Goals (MCLGs), (2) Federal Health Advisories, (3) California Department of Health Services Action Levels, (4) California Inland Surface Waters Plan, Numerical Water Quality Objectives, (5) California Proposition 65 Regulatory Levels as Water Quality Criteria, and (6) the National Pollutant Discharge Elimination System (NPDES) permit for the groundwater treatment plant at McClellan Air Force Base (McClellan AFB).

The Safe Drinking Water Act, 42 USC §300(f), et seq., provides limits on the concentrations of certain hazardous materials in drinking water "at the tap." The Act establishes both MCLs, which are enforceable limits, and maximum contaminant level goals, which are not enforceable against drinking water providers. When cleaning up an aquifer, EPA selects levels that are at least as protective as MCLs, and to the greatest extent possible, that are at least as protective as non-zero MCLGs.

Table G-1
Potential Chemical-Specific ARARs for the Davis Site
VOCs
(Concentrations in µg/l = ppb, unless noted otherwise)

Compound	ARARs					Other Criteria To Be Considered					
	Drinking Water Standards					U.S. EPA Health Advisories (70 kg)		CA DHS Action Level	CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen		California Proposition 65
	CA DHS		EPA			RfD			Drinking Water	Other Waters	
	Primary MCL	Secondary MCL	Primary MCL	Secondary MCL	MCLG	ug/kg/day	Lifetime				
1,1,1-TRICHLOROETHANE	200	--	200	--	200	35	200	--	200 (a)	11,000 (a)	--
1,1,2,2-TETRACHLOROETHANE	1	--	--	--	--	--	--	--	0.17* (a)	11* (a)	1.5
1,1,2-TRICHLORO-1,2,2-TRICHLOROFLUOROETHANE	1,200	--	--	--	--	--	--	--	--	--	--
1,1-DICHLOROETHANE	5	--	--	--	--	--	--	--	--	--	50
1,2,4-TRIMETHYLBENZENE	--	--	--	--	--	--	--	--	--	--	--
1,1-DICHLOROETHENE	6	--	7	--	7	9	7	--	0.057* (a)	3.2* (a)	--
1,3,5-TRIMETHYLBENZENE (MESITYLENE)	--	--	--	--	--	--	--	--	--	--	--
1,2-DICHLOROETHANE	0.5	--	5	--	0	--	--	--	0.5* (a)	130* (a)	5
1,3-DICHLOROBENZENE	--	--	600	--	600	89	600	136* (b)	400	2,600	--
1,4-DICHLOROBENZENE	5	--	75	5 (a)	75	100	75	--	9.9*	6.4*	10
4-METHYL-2-PENTANONE	--	--	--	--	--	--	--	--	--	--	--
ACETONE	--	--	--	--	--	100	--	--	--	--	--
BENZENE	1	--	5	--	0	--	--	--	0.34*	21*	3.5
BENZYL BUTYL PHTHALATE	--	--	100 (a)	--	--	--	--	--	--	--	--
BROMOMETHANE	--	--	--	--	--	1	10	--	100* (c)	480* (c)	--
CHLOROETHANE	--	--	--	--	--	--	--	--	--	--	100 (a)
CHLOROFORM	100 (d)	--	100 (d)	--	--	10	--	--	100*	480*	10
CHLOROMETHANE	--	--	--	--	--	4	3	--	100* (c)	480* (c)	10
CIS-1,2-DICHLOROETHENE	6	--	70	--	70	10	70	--	--	--	--
DICHLORODIFLUOROMETHANE	--	--	--	--	--	200	1	--	--	--	--
DIESEL PETROLEUM HYDROCARBONS	--	--	--	--	--	--	--	--	--	--	--
ETHYLBENZENE	680	--	700	30 (a)	700	100	700	--	680 (a)	29,000(a)	--
METHYLENE CHLORIDE	--	--	5 (c)	--	0 (c)	60	--	40	4.6*	1,600*	25
TETRACHLOROETHENE	5	--	5	--	0	10	--	--	0.62* (a)	6.9* (a)	7
TOLUENE	--	--	1,000	40 (a)	1,000	200	1,000	100	10,000	300,000	3,500 (f)
TOTAL 1,2-DICHLOROETHENE	--	--	--	--	--	--	--	--	--	--	--

Table G-1
Potential Chemical-Specific ARARs for the Davis Site
VOCs
(Concentrations in µg/l = ppb, unless noted otherwise)

Compound	ARARs: Drinking Water Standards: CA DHS: Primary MCL	ARARs: Drinking Water Standards: CA DHS: Secondary MCL	ARARs: Drinking Water Standards: EPA: Primary MCL	ARARs: Drinking Water Standards: EPA: Secondary MCL	ARARs: Drinking Water Standards: EPA: MCLG	Other Criteria To Be Considered: U.S. EPA Health Advisories (70 kg): RfD ug/kg/day	Other Criteria To Be Considered: U.S. EPA Health Advisories (70 kg): Lifetime	Other Criteria To Be Considered: CA DHS Action Level	Other Criteria To Be Considered: CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen: Drinking Water	Other Criteria To Be Considered: CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen: Other Waters	Other Criteria To Be Considered: California Proposition 65
TOTAL XYLENES	1,750	--	10,000	20 (a)	10,000	2,000	10,000	--	--	--	--
TRICHLOROETHENE	5	--	5	--	0	--	--	--	--	--	25
TRICHLOROFLUOROMETHANE	150	--	--	--	--	300	--	150	--	--	--
VINYL CHLORIDE	0.5	--	2	--	0	--	--	--	.13* (a)	34* (a)	1.5

(a) Proposed

(b) Action Level is for a single isomer or sum of isomers

(c) Sum of bromoform, bromomethane, chloromethane, dibromochloromethane, and bromodichloromethane

(d) For total trihalomeththanes based largely on technology and economics.

(e) Effective 17 Jan 94

(f) Based on reproductive toxicity

NOTES:

-- = not listed

Abbreviations:

DHS	Department of Health Services.
MCL	Maximum Contaminant Level.
MCLG	Maximum Contaminant Level Goal.
RfD	References Doses.

U.S. EPA Health Advisories:

Lifetime (70kg) = Concentraion of compound in drinking water that could pose a risk if consumed by a 70-kg adult for a lifetime.

Source Documents:

(1) Drinking Water Regulations and Health Advisories by Office of Water/EPA, December 1992

(2) Region IX/U.S. EPA, Drinking Water Standards and Health Advisories Table, December 1992

(3) California Regional Water Quality Control Board. A Compilation of Water Quality Goals. May 1993

Table G-2
Potential Chemical-Specific ARARs for the Davis Site
Semi-VOCs/Pesticides/Other
(Concentrations in µg/l = ppb, unless noted otherwise)

	ARARS					Other Criteria To Be Considered					
	Drinking Water Standards					U.S. EPA Health Advisories (70 kg)			CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen		
	CA DHS		EPA			RfD		CA DHS			Proposition
Compound	Primary MCL	Secondary MCL	Primary MCL	Secondary MCL	MCLG	ug/kg day	Lifetime	Action Level	Drinking Water	Other Waters	65
2-METHYLNAPHTHALENE	--	--	--	--	--	--	--	--	--	--	--
ACENAPHTHENE	--	--	--	--	--	--	--	--	--	--	--
ANTHRACENE	--	--	--	--	--	300	--	--	0.0028* (a)	0.031* (a)	--
BIS(2-ETHYLHEXYL)PHTHALATE	4	--	6 (b)	--	--	--	--	--	--	--	--
DI-N-BUTYLPHTHALATE	--	--	--	--	--	--	--	--	--	--	--
DIBENZOFURAN	--	--	--	--	--	--	--	--	--	--	--
DIETHYLPHTHALATE	--	--	--	--	5,000 (c)	--	--	--	23,000 (c)	120,000 (c)	--
ETHYLENE DIBROMIDE (EDB)	0.02	--	0.05	--	0	--	--	--	--	--	--
FLUORENE	--	--	--	--	--	--	--	--	0.0028* (a)	0.031* (a)	--
NAPHTHALENE	--	--	--	--	--	4	20	--	--	--	--
PH	--	--	--	5.5 TO 8.5 UNITS	--	--	--	--	--	--	--
PHENANTHRENE	--	--	--	--	--	--	--	--	0.0028* (a)	0.031* (a)	--
PYRENE	--	--	--	--	--	--	--	--	0.0028* (a)	0.031* (a)	--
TOTAL DISSOLVED SOLIDS	--	500,000 (c)	--	500,000		--	--	--	--	--	--

(a) For sum of acenaphthylene, anthracene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, fluorene, indeno(1,2,3-c,d)pyrene, phenanthrene, and pyrene

(b) Effective 17 January 1994

(c) Proposed

NOTES:

-- = not listed

Abbreviations:

DHS	Department of Health Services.
MCL	Maximum Contaminant Level.
MCLG	Maximum Contaminant Level Goal.
RfD	References Doses.

U.S. EPA Health Advisories:

Lifetime (70kg) = Concentration of compound in drinking water that could pose a risk if consumed by a 70-kg adult for a lifetime.

Source Documents:

(1) Drinking Water Regulations and Health Advisories by Office of Water/EPA, December 1992

(2) Region IX/U.S. EPA, Drinking Water Standards and Health Advisories Table, December 1992

(3) California Regional Water Quality Control Board. A Compilation of Water Quality Goals, May 1993

Table G- 3
Potential Chemical-Specific ARARs for the Davis Site
Metals
(Concentrations in µg/l = ppb, unless noted otherwise)

	ARARS					Other Criteria To Be Considered					
	Drinking Water Standards					U.S. EPA Health Advisories (70 kg)			CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen		
	CA DHS		EPA					CA DHS			California
Compound	Primary MCL	Secondary MCL	Primary MCL	Secondary MCL	MCLG	RfD ug/kg/day	Lifetime	Action Level	Drinking Water	Other Waters	Proposition 65
ALUMINUM	1,000	--	--	50 to 200	--	--	--	--	--	--	--
ANTIMONY	--	--	6 (a)	--	6 (a)	0.4	3	--	14 (b)	4,300 (b)	--
ARSENIC	50	--	50	--	--	0.3	--	--	5*	--	5
BARIUM	1,000	--	2,000	--	2,000	70	2,000	--	--	--	--
BERYLLIUM	--	--	4 (a)	--	--	5	--	--	0.008* (b)	0.13* (b)	(c)
CADMIUM	10	--	5	--	5	0.5	--	--	10	--	(c)
CALCIUM	--	--	--	--	--	--	--	--	--	--	--
CHROMIUM	50	--	100	--	100	5	100	--	50 (d)	--	--
CHROMIUM, HEXAVALENT	--	--	--	--	--	--	--	--	50 (d)	--	(c)
COBALT	--	--	--	--	--	--	--	--	--	--	--
COPPER	--	1,000	1,300 (e)	--	1,300	--	--	--	1,000 (f)	--	--
IRON	--	--	--	--	--	--	--	--	--	--	--
LEAD	50	--	15 (e)	--	0	--	--	--	50	--	0.25 (g)
MAGNESIUM	--	--	--	--	--	--	--	--	--	--	--
MANGANESE	--	50	--	--	--	140	--	--	--	--	--
MERCURY	2	--	2	--	2	0.3	2	--	0.012	0.012	--
MOLYBDENUM	--	--	--	--	--	5	40	--	--	--	--
NICKEL	--	--	100 (a)	--	100 (a)	20	100	--	600	4,600	(c)
POTASSIUM	--	--	--	--	--	--	--	--	--	--	--
SELENIUM	10	--	50	--	50	5	--	--	10	--	--
SILVER	50	--	100	--	--	5	100	--	50	--	--
SODIUM	--	--	--	--	--	--	--	--	--	--	--
THALLIUM	--	--	2 (a)	--	0.5 (a)	0.07	0.4	--	1.7 (b)	6.3 (b)	--
TOTAL CYANIDE	--	--	200 (a)	--	200(a)	22	200	--	700(b)	220,000(b)	--
VANADIUM	--	--	--	--	--	3	20	--	--	--	--

Table G- 3
Potential Chemical-Specific ARARs for the Davis Site
Metals
(Concentrations in µg/l = ppb, unless noted otherwise)

Compound	ARARS: Drinking Water Standards: CA DHS: Primary MCL	ARARS: Drinking Water Standards: CA DHS: Secondary MCL	ARARS: Drinking Water Standards: EPA: Primary MCL	ARARS: Drinking Water Standards: EPA: Secondary MCL	ARARS: Drinking Water Standards: EPA: MCLG	Other Criteria To Be Considered: U.S. EPA Health Advisories (70 kg): RfD ug/kg/day	Other Criteria To Be Considered: U.S. EPA Health Advisories (70 kg): Lifetime	Other Criteria To Be Considered: CA DHS Action Level	Other Criteria To Be Considered: CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen: Drinking Water	Other Criteria To Be Considered: CA Inland Surface Waters Plan Human Health Protection (30-day average) *=carcinogen: Other Waters	Other Criteria To Be Considered: California Proposition 65
ZINC	--	5,000	--	5,000	--	300	2,000	--	--	--	-

(a) Effective 17 Jan 94

(b) Proposed

(c) Determined not to pose a risk of cancer through ingestion (Title 22, CCR, Division 2)

(d) Value developed for Chromium VI; may be applied to total chromium if valence unknown

(e) MCL includes this "Action Level," to be exceeded in no more than 10% of samples

(f) Based on organoleptic considerations (taste, odor, color, etc.)

(g) Based on reproductive toxicity

NOTES:

-- = not listed

Abbreviations:

DHS	Department of Health Services.
MCL	Maximum Contaminant Level.
MCLG	Maximum Contaminant Level Goal.
RfD	References Doses.

U.S. EPA Health Advisories:

Lifetime (70kg) = Concentration of compound in drinking water that could pose a risk if consumed by a 70-kg adult for a lifetime.

Source Documents:

(1) Drinking Water Regulations and Health Advisories by Office of Water/EPA, December 1992

(2) Region IX/U.S. EPA, Drinking Water Standards and Health Advisories Table, December 1992

(3) California Regional Water Quality Control Board. A Compilation of Water Quality Goals, May 1993

In determining whether the SDWA applies to the groundwater underlying the Davis Site, the groundwater classification and beneficial uses must first be identified. EPA's policy for groundwater classification is set forth in the preamble to the National Contingency Plan (NCP) (55 Federal Register 8752-8756). This policy uses the groundwater classification system provided in the EPA *Guidelines for Groundwater Classification under the EPA Groundwater Protection Strategy* (U.S. EPA, 1986). Under this policy, groundwater is classified in one of three categories (Class I, II, and III) based on ecological importance, replaceability, and vulnerability considerations. Irreplaceable groundwater that is currently used by a substantial population or groundwater that supports a vital habitat is considered Class I. Class II groundwater consists of groundwater that is currently being used or water that might be used as a source of drinking water in the future. Groundwater that cannot be used for drinking water due to insufficient quality (e.g., high salinity or widespread naturally occurring contamination) or quantity is considered to be Class III. The beneficial uses for the groundwater at the Davis Site, as designated by the Regional Water Quality Control Board, include municipal, agricultural, industrial, and domestic water supply. On the basis of these beneficial uses, the groundwater could be classified as a Class II aquifer because it has in the past, and may in the future, be used as a source of drinking water.

CERCLA §121(d)(2)(B) provides that CERCLA response actions "shall require a level or standard of control which at least attains Maximum Contaminant Level Goals established under the Safe Drinking Water Act." The SDWA MCL standards are based on human consumption of water for drinking, cooking, bathing, and other similar uses. Economic considerations and technical feasibility of treatment processes are included in the justification for these levels. MCLs are applicable to the quality of drinking water at the tap pursuant to the SDWA and are ARARs for treated groundwater when the end use is drinking water. California Department of Health Services MCLs are enforced if the levels are stricter than the SDWA MCLs.

MCLs may also be used as water quality limits for bodies of water designated as sources of drinking water in a Water Quality Control Plan. Because the Water Quality Control Plan for the Central Valley Region considers the beneficial uses of the groundwater in the Davis area to include domestic water supply, MCLs may be applied to treated groundwater that is or could potentially be used as a source of drinking water.

MCLGs are established by EPA under the National Primary Drinking Water Regulations and are the first step in establishing MCLs. These goals are set at levels which represent no adverse health risks. MCLGs are set at zero for known and probable human carcinogens.

Pursuant to 40 CFR Section 300.430(e)(2)(i)(B), MCLs and nonzero MCLGs are relevant and appropriate as in situ aquifer standards for groundwater that is or may be used for drinking water.

EPA MCLs are the only federally enforceable drinking water regulations in Tables G-1, G-2, and G-3. Some compounds have California MCLs, which are also enforceable because they are more strict than the EPA MCLs. The other criteria discussed below are nonenforceable goals or advisories that are derived from health- related data or information.

Many compounds in the tables have multiple standards and criteria. In the absence of an MCL value, the more stringent TBC may apply. However, MCLs and TBCs do not consider the mixture of chemicals that are present at the Davis Site and therefore cleanup goals may be set below the chemical-specific requirements to adequately protect human health and the environment.

Federal Health Advisories are TBC criteria published by EPA's Office of Drinking Water. The lifetime health advisory (HA) numerical value is calculated using a 70 kilogram adult who consumes 2 liters of water per day. A relative source contribution from water is also factored into the lifetime HA calculation. HAs are draft documents which are subject to change as new information becomes available.

The Reference Dose (RfD) is a daily exposure level which appears to be without appreciable risk during the lifetime of a human. The units of the RfD are micrograms per kilogram per day. The RfD is derived from a "no observed adverse effect level" (NOAEL) identified from an applicable animal study. These values are not ARARs, but are TBC criteria.

The California Department of Toxic Substances Control (DTSC) (formerly known as the Department of Health Services, or DHS) has developed drinking water action levels as guidelines for the protection of drinking water systems. These levels are advisory, not regulatory, and can be used as guidance where corrective action may be required. These values are also TBC criteria.

The Regional Water Quality Control Board (RWQCB) has developed a Basin Plan for the Central Valley Region that establishes the beneficial uses of specific water bodies within the region. To protect these beneficial uses, the State Water Resources Control Board has adopted the Inland Surface Waters Plan. This plan establishes water quality objectives for receiving waters to protect sources of drinking water and aquatic life from various pollutants. Only values developed for the protection of human health are listed on Tables G-1 through G-3. Values to protect aquatic life have been developed for metals, but have not yet been developed for many organic compounds, which are the contaminants of concern (i.e., VOCs) at the Davis Site. These TBC values may be applied to treated groundwater discharged to surface water or runoff that may reach local streams during construction activities at the site. The Inland Surface Waters Plan also may apply to runoff from crops irrigated with treated groundwater.

The Safe Drinking Water and Toxic Enforcement Act (also known as Proposition 65) establishes a discharge prohibition and warning requirement for carcinogens and reproductive toxins. Under Health and Safety Code §25249.5, "No person in the

course of doing business shall knowingly discharge or release a chemical known to the State to cause cancer or reproductive toxicity into waters or onto or into land where such chemical passes or probably will pass into any source of drinking water...." Health and Safety Code §25249.6 prohibits any person in the course of business from exposing an individual to such a carcinogen or reproductive toxin without first providing a clear and reasonable warning. Regulations in 22 CCR §12000, et seq., establish "no significant risk" levels or "safe use numbers" for chemicals subject to the act.

EPA has previously considered whether Proposition 65 is an ARAR for federal Superfund sites and has concluded it is not an ARAR because it does not impose a more stringent level of control than Federal ARARs. However, these values are TBCs.

The NPDES permit that was issued by the Regional Water Quality Control Board (RWQCB) for the groundwater treatment plant at McClellan AFB may be considered TBC criteria because it sets limitations for VOCs in the treated effluent. The limitations are 1 μg/l for acetone, methylethylketone, and methyl isobutyl ketone, and nondetect or 0.5 μg/l for all other VOCs. The regulations used to develop the McClellan AFB permit would be the same as those that would be applied to the Davis Site.

EPA does not have set chemical-specific cleanup criteria for soil that would be considered ARARs. EPA Region IX has drafted Preliminary Remedial Goals (PRGs) for soil which were issued in April 1993 and updated on August 6, 1993. PRGs are health-based concentrations that can be used as triggers for further investigation or as initial cleanup goals if applicable. These draft remedial goals are currently under revision and are not considered ARARs. They are, however, TBC criteria.

Toxicity characteristic leaching procedure (TCLP) criteria have been adopted under 40 CFR 261.24 to determine when a waste will be defined as a characteristic RCRA waste due to toxicity. These criteria set a regulatory limit at which the material must be managed and treated as a RCRA hazardous waste. TCLP criteria are applicable to all wastes, such as contaminated soil boring cuttings, generated at the Davis Site which are taken offsite for disposal.

Cal/EPA Hazardous Waste Characterization criteria may also apply to contaminated media removed from the site for disposal. Hazardous waste and extremely hazardous waste criteria include Soluble Threshold Limit Concentration (STLC) and Total Threshold Limit Concentration (TTLC) (Title 22, CCR, Chapter 11). These concentrations are used to determine whether a waste is considered hazardous or extremely hazardous for the purposes of treatment, storage, transportation, and disposal.

Tables G-1 through G-3 do not include the TCLP, TTLC or STLC values since excavation and offsite disposal of soil as a remedial alternative is not an option. These hazardous waste criteria will be applicable only if contaminated media is taken offsite

for disposal. Tables G-1 through G-3 also do not include chemical-specific requirements for air emissions. Selected air emission requirements are discussed under action-specific and non-specific ARARs.

Location-Specific ARARs

Potential location-specific ARARs and other criteria for the Davis Site are listed in Table G-4. Location-specific ARARs differ from chemical-specific or action-specific ARARs in that they are not closely related to the site's waste characteristics or to the specific remedial alternative under consideration. Location-specific ARARs are concerned with the area in which the site is located. Actions may be required to preserve or protect aspects of the area's environment or cultural resources that may be threatened by the site's existence or by the proposed remedial actions.

The major statutes from which the regulations are derived which contribute to the list of potential location-specific ARARs include:

- Resource, Conservation and Recovery Act
- National Archaeological and Historic Preservation Act
- National Historic Preservation Act
- Endangered Species Act
- Clean Water Act
- Wilderness Act
- Fish and Wildlife Coordination Act
- Scenic Rivers Act
- Coastal Zone Management Act
- Marine Protection Resources and Sanctuary Act

Two executive orders are also included: the Executive Order on the Protection of Wetlands, and the Executive Order on Protection of Flood Plains. R18-8-264.18 (40 CFR 264.18(b)) applies to the citing of new hazardous waste treatment facilities within the 100-year flood plain.

To the extent that the remedial action will affect historical resources, streams, flood plains, or wetlands, Cal/EPA requires that the potential remedial alternatives comply with the location-specific requirements. The major statutes and regulations included in the list of potential location-specific ARARs are described below.

Executive Order on Flood Plain Management

The Executive Order on Flood Plain Management requires Federal agencies to evaluate the potential effects of actions that may take place in a flood plain to avoid, to the extent possible, adverse effects associated with direct and indirect flood plain development. EPA's regulations to implement this Executive Order are set forth in 40 CFR 6 §6.302(b). In addition, EPA has developed guidance entitled "Policy on Flood Plains and Wetlands Assessments for CERCLA Actions," dated August 6, 1985.

Table G-4
Potential Location-Specific ARARs
for the Davis Site

Location	Requirement/Prerequisite	Citation	Comment	Applicability
1. Within 61 meters (200 feet) of a fault displaced in Holocene time	All treatment, storage, and disposal of hazardous wastes is prohibited within 200 feet of a Holocene fault.	40 CFR 264.18(a) 22 CCR 66264.18(a) 23 CCR 2531(d)	There is no evidence of an active fault within 61 meters of the site.	Not ARAR
2. Within 100-year flood plain	Treatment, storage, and disposal for hazardous wastes must be constructed to avoid washouts if located in a 100-year flood plain. Land treatment and disposal units for hazardous wastes may not be located in a 100-year flood plain.	40 CFR 264.18(b) 23 CCR 2531(c) 22 CCR 66264.18(b) 22 CCR 66270.14(b)(11) Fish and Game Code 1600 et seq.	Part of the Davis Site (southeast) is located within a 100-year flood plain. No new permanent building is proposed in the 100-year flood plain zone. A RCRA facility located in a 100-year flood plain must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by a 100-year flood. Work within the 100-year flood plain will require notification of the Department of Fish and Game prior to such work.	Potential ARAR
3. Within flood plain	Relates to actions that will occur in a flood plain, i.e., lowlands, and relatively flat areas adjoining inland and coastal waters and other flood-prone areas. Actions must be taken to avoid adverse effects, minimize potential harm, restore and preserve natural and beneficial values.	Executive Order 11988, Protection of Flood Plains 40 CFR 6, §6.302(b)	Federal agencies are directed to ensure that planning programs and budget requests reflect consideration of flood-plain management, including the restoration and preservation of such land as natural undeveloped flood plains. If newly constructed facilities are to be located in a flood plain, accepted flood-proofing and other flood control measures shall be undertaken to achieve flood protection. Whenever practical, structures shall be elevated above the base flood level rather than filling land. As part of any federal plan or action, the potential for restoring and preserving flood plains so their natural beneficial values can be realized must be considered.	Potential ARAR
4 Within salt dome formation, underground mine, or cave	If a RCRA hazardous waste, placement of non-containerized or bulk liquid hazardous waste prohibited.	40 CFR 264.18(c) 22 CCR 66264.18(c)	The Davis Site does not contain any salt dome formation, underground mine, or caves used for waste disposal. No such disposal is planned.	Not ARAR
5 Within area where action may cause irreparable harm, loss, or destruction of significant artifacts	Alteration of terrain threaten significant scientific, prehistorical, historical, or archaeological data. Action must be taken to recover and preserve artifacts applicable to federal projects on public land only. Provides for the preservation of historical and archaeological data.	National Archaeological and Historical Preservation Act (16 USC Section 469); 36 CFR Part 65	The proposed remedial alternatives will not alter or destroy any known prehistoric or historic archaeological features of the Davis Site. Until detailed information is received from those with expertise in local archaeological studies, no conclusion or recommendation can be reached. (McClelian AFB Comprehensive Plan, 1987)	Potential ARAR

Table G-4
Potential Location-Specific ARARs
for the Davis Site

	Location	Requirement/Prerequisite	Citation	Comment	Applicability
6	Historic project owned or controlled by federal agency	If property is included in or eligible for the National Register of Historic Places, actions must be taken to preserve historic properties; planning of action to minimize harm to National Historic Landmarks	National Historic Preservation Act Section 106 (16 USC 470 *et seq.*); 36 CFR Part 800	As buildings reach 50 years of age, they will be evaluated for historic status. The proposed remedial alternatives will not have any impacts on the existing buildings.	Potential ARAR
7	Critical habitat upon which endangered species or threatened species depends	Requires action to conserve endangered species or threatened species, including consultation with the Department of the Interior, Fish and Wildlife Service. Same as federal requirement but includes required consultation with California Department of Fish and Game. Lists species of birds protected by four treaties between U.S. and Canada, Mexico, Japan, and Russia.	Endangered Species Act of 1973 (16 USC 1531 *et seq.*); 50 CFR Part 200, 50 CFR Part 402 California Endangered Species Act California Fish and Game Code Sections 2070, 2080, 2090-2096 14 CCR Section 670.5 Migratory Bird Treaty Act (16 USC 703-712) with list of protected birds in 50 CFR 10.13.	Special status species identified by the California Natural Diversity Data Base as occurring in the Davis Site vicinity are Swainson's Hawk and Burrowing Owl. Five plant species of concern have been observed on the Davis Site. These are alkali milkvetch, Colusa grass, Solano grass, vernal pool dodder, and alkali peppergrass. Colusa grass has been listed as an endangered species in California and Solano grass is listed as an endangered species by the U.S. Fish and Wildlife Service and by the State of California. The proposed remedial alternatives will have no effect on botanical or wildlife resources, wetlands, threatened or endangered, or special-status species. The analysis to support this conclusion is found in the Site Remediation Initial Study for the Davis Global Communication Site by CH2M HILL, dated June 21, 1993.	Potential ARAR
8	Wetlands	Wetlands are defined by Executive Order 11990 Section 7. Requires action to minimize the destruction, loss, or degradation of wetlands. Action to prohibit discharge of dredged or fill material into wetlands without permit.	Executive Order 11990, Protection of Wetlands (40 CFR 6, §6.302(a) Clean Water Act Section 404, 40 CFR Parts 230, 231 Porter-Cologne Water Quality Control Act California Fish & Game Code Section 1603	If wetlands are located within the area of proposed federal activities, the agency must conduct a Wetlands Assessment to identify wetlands and potential means of minimizing impacts. If there is no practical alternative to locating in or affecting the wetland, the Agency shall act to minimize potential harm to the wetland. The Clean Water Act prohibits discharge of dredged or fill material into wetlands without a permit. Seasonal wetlands formed from winter rains (less than 1 acre) were located east of the fenced compound near the center of the Davis Site. No major disturbances or construction activities are anticipated in the project area that would have an adverse impact on the seasonal wetlands.	Potential ARAR

Table G-4
Potential Location-Specific ARARs
for the Davis Site

Location	Requirement/Prerequisite	Citation	Comment	Applicability
9. Wilderness area	Areas federally owned and designated as wilderness areas must be administered in such a manner as will leave it unimpaired as wilderness and to preserve its wilderness character.	Wilderness Act (16 USC 1131 *et seq.*); 50 CFR 35.1 *et seq.*	The Davis Site is not within or adjacent to any federally designated wilderness area.	Not ARAR
10. Wildlife refuge	If an area is designated as part of National Wildlife Refuge System, only actions allowed under the provisions of 16 USC Section 668 dd(c) may be undertaken in areas that are part of the National Wildlife Refuge System.	16 USC 668 dd *et seq.*; 50 CFR Part 27	The Davis Site is not designated as part of the National Wildlife Refuge System.	Not ARAR
11. Area affecting stream or river	Diversion, channeling, or other activity that modifies a stream or river and affects fish or wildlife will require actions to protect fish or wildlife. Diversions, channeling, or any other activity that affects a stream or watercourse is controlled. The Department of Fish and Game has primary responsibility for the protection of California's fish and wildlife resources.	Fish and Wildlife Coordination Act (16 USC 661 *et seq.*); 40 CFR 6.302 California Fish & Game Code	Proposed activities are not expected to alter or divert the streams or waterways within or around the Davis Site.	Not ARAR Not ARAR
12. Within coastal zone	Applies to activities affecting the coastal zone including lands thereunder and adjacent shorelands. Applies to activities affecting the coastal zone including lands thereunder and adjacent shorelands.	Coastal Zone Management Act (16 USC Section 1451 *et seq.*) California Coastal Act of 1976 (PRC Div 20 Sections 30,000 *et seq.*)	The Davis Site is an inland area with no direct access to coastal areas. The Davis Site is an inland area with no direct access to coastal areas.	Not ARAR Not ARAR
13. Within area affecting national wild, scenic, or recreational river	Activities that affect or may affect any of the rivers specified in Section 1276(a). Avoid taking or assisting in action that will have direct adverse effect on scenic river.	Scenic Rivers Act (16 USC 1271 *et seq.* Section 7(a)); 40 CFR 6.302(e) California Wild and Scenic Rivers	No national wild or scenic rivers are located on the Davis Site or will be impacted by proposed remediation.	Not ARAR

Table G-4
Potential Location-Specific ARARs
for the Davis Site

Location	Requirement/Prerequisite	Citation	Comment	Applicability
14 Oceans or waters of the United States	Applies to oceans and waters of the United States, and action to dispose of dredge and fill material into ocean waters is prohibited without a permit.	Clean Water Act (Section 404 40 CFR 125) Subpart M, Marine Protection Resources and Sanctuary Act Section 103 Porter Cologne Water Quality Control Act	Proposed activities do not include dredging or sediment removal.	Not ARAR
15 Sole source aquifer	Protection of aquifer through federal assistance funding. Applies to aquifers that are sole or principal drinking water sources and if contaminated would present a significant hazard to public health. Prohibits injection of waste.	SDWA 42 USC Section 300h; 40 CFR Section 146.4	Activities will not affect principal drinking water sources.	Not ARAR
16 Hazardous waste site	Actions to limit worker exposure to hazardous wastes or hazardous substances, including training or monitoring	29 CFR 1910.120	Precautions will be made to ensure employee safety.	Potential ARAR
17 Security	Unknowing and unauthorized entry to active portion of the facility shall be prevented.	22 CCR 66264.14	The Davis Site comprises approximately 316 acres; activities related to the proposed remedial alternatives would occur within the fenced compound near the middle of the site and within the northernmost quarter of the site. The northernmost area will be fenced if physical contact with any waste, structures, or equipment within the active portion of that area could potentially injure unknowing or unauthorized persons or livestock which might enter.	Potential ARAR

Note: This table identifies potential location specific ARARs and TBCs for the remedial action alternatives presented in this RI/FS. Actual ARARs for the selected remedial actions for the Davis Site will be identified in the Record of Decision.

Archeological and Historic Preservation Act

The Archeological and Historic Preservation Act establishes procedures to provide for historical and archeological data preservation which might be destroyed through terrain alteration as a result of a Federal construction project or a Federally licensed activity or program. If proposed remedial action activities would cause irreparable loss or destruction of significant scientific, prehistorical, historical, or archeological data, Cal/EPA would require adherence to the procedures in the statute to provide for data recovery and preservation activities.

National Historic Preservation Act

The National Historic Preservation Act requires Federal agencies to take into account the effect of any Federally assisted undertaking or licensing on any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register of Historic Places. As buildings at the Davis Site reach 50 years of age, they will be evaluated for historic status in accordance with 36 CFR 800.4, Section 1906. None of the buildings onsite are 50 years of age. They were constructed during the 1950s. No other archaeological or cultural resources have been indicated at the Davis Site.

No structures are to be impacted by the proposed remedial alternatives. If an eligible structure would have been adversely affected, the procedures for protection of historic properties are set forth in Executive Order 11593 entitled "Protection and Enhancement of the Cultural Environment" and in 36 CFR Part 800, 36 CFR Part 63, and 40 CFR §6.301(c). These procedures are potentially relevant and appropriate for any action that might impact historic properties.

Executive Order on Protection of Wetlands

The Executive Order on Protection of Wetlands requires Federal agencies to avoid, to the extent possible, the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands if a practicable alternative exists. EPA's regulations to implement this Executive Order are set forth in 40 CFR 6, §6.302(a). In addition, EPA has developed guidance entitled "Policy on Flood Plains and Wetlands Assessments for CERCLA Actions," dated August 6, 1985. Seasonal wetlands were found east of the fenced compound near the center of the Davis Site. These wetlands were probably formed from winter rains and cover less than 1 acre of the site. This area is outside the area of proposed remedial alternatives.

Federal and State Waste Management Regulations

Both Federal and State solid and hazardous waste statutes have requirements pertaining to location of facilities in flood plain areas. No permanent structures are proposed as part of the remedial alternatives with the exception of a potential irrigation

storage reservoir and possible small-scale treatment plants. The proposed remedial alternatives would not expose people or property to water-related hazards such as flooding and would be located away from the flood-plain area that encroaches into the southeast section of the site. No new permanent buildings are planned in the 100-year flood plain. To the extent that the remedy involves storage or disposal of solid wastes, the Federal and State requirements governing siting and operation of facilities in the flood plain would be potentially relevant and appropriate.

Endangered Species Act

Under the Endangered Species Act, remedial actions must avoid jeopardizing the continued existence of listed endangered or threatened species or modification of their habitat. If a listed species or their habitat may be affected by a remedial action, consultation with the Fish and Wildlife Service may be necessary. Special-status wildlife include Swainsons Hawks and Burrowing Owls. The proposed remedial actions will have a less than significant impact on wildlife populations at the site.

Information regarding rare and endangered plants at the Davis Site was provided to CH2M HILL by McClellan AFB. Five plant species of special concern were identified at the site. These species include alkali milkvetch, vernal pool dodder, alkali peppergrass, Colusa grass, and Solano grass. Colusa grass has been listed as endangered in California and was identified in two seasonal wetland areas located along the eastern- and western-most edges of the property.

Solano grass was found at either end of a seasonal wetland area that runs along the west edge of the property, south of the compound area, and along the south edge of the property. Solano grass is listed as an endangered species by the U.S. Fish and Wildlife Service and by the State of California. This is the first population of Solano grass to be discovered in Yolo County and only the third population known to science. These two sub-populations (shown in Figure G-1) at the Davis Site total many thousands of individual plants.

Construction and installation of extraction, treatment, and end-use facilities and equipment will not affect the endangered botanical species found at the Davis Site. No new facilities are planned in the areas where these grasses are located.

Action-Specific ARARs

The vadose zone and groundwater remedial alternatives and end-use options under consideration are listed on the Table G-5.

The potential action-specific ARARs that relate to the remedial alternatives and end use options listed above for the Davis Site are presented in Table G-6. The action-specific ARARs include technology- and activity-based requirements or limitations on actions taken with respect to hazardous substances at the site.

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FIGURE G-
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FIGURE G-1
ENDANGERED GRASS LOCATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2M HILL

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Table G-5 Vadose Zone and Groundwater Remedial Alternatives and End-Use Options		
Options	Media	
	Vadose Zone	Groundwater
Capture Alternatives	• Soil vapor extraction • Bioventing	• Groundwater extraction
Treatment Options	• Electron beam technology • Adsorptive media • Catalytic oxidation	• Advanced ultraviolet oxidation • Granular-activated carbon • Air stripping
End Use Options	• Air discharge	• Irrigation • Reinjection

For each action, a number of potential action-specific ARARs that may be applicable or relevant and appropriate to implementation of the remedial action have been identified. A description of the requirements associated with each potential ARAR and a discussion of the conditions under which the ARAR would be applicable or relevant and appropriate are included.

In addition to the action-specific requirements discussed in Table G-6, there are a number of regulations or requirements that also contain chemical- and location-specific aspects. These regulations or requirements may be considered relevant or appropriate to several potential remedial alternatives. A more detailed discussion of some of these ARARs is presented below.

Resource Conservation and Recovery Act

Many RCRA requirements are applicable or relevant and appropriate to the alternatives presented herein. The RCRA program is a delegable program; the states may manage the program in lieu of the EPA if the state statutes and regulations are equivalent to or more stringent than the federal statutes and regulations. California is authorized to manage the RCRA "base" program, i.e., the requirements in existence before the passage of the Hazardous and Solid Waste Amendments (HSWA) of 1984. The EPA enforces the requirements promulgated pursuant to HSWA. Therefore, in some cases the applicable or relevant and appropriate RCRA requirement will be cited as state law and in other cases as federal law.

"Contained in" Interpretation

The EPA's "contained in" interpretation provides that an environmental medium (e.g., soil, groundwater, debris, surface water) that has been contaminated by a listed hazardous waste above a risk-based level or a level of concern must be managed as if it were a hazardous waste. Therefore, the RCRA regulations may be applicable or relevant and appropriate to the management of a contaminated environmental medium.

Table G-6
Potential Action-Specific ARARs
for the Davis Site

Action	Requirement/Prerequisite	Citation	Applicability	Comments
Container Storage (Onsite)	Containers holding RCRA hazardous waste (listed or characteristic) for a temporary period before treatment, disposal, or storage elsewhere (40 CFR 264.10) must be:			These requirements are applicable or relevant and appropriate for any contaminated soil or groundwater or treatment system waste that might be containerized and stored onsite prior to treatment or final disposal. Groundwater or soil containing a listed waste must be managed as if it were a hazardous waste so long as it contains the listed waste.
	• Maintained in good condition	40 CFR 264-171 (R18-18-264.170, et seq.)	ARAR	
	• Compatible with hazardous waste to be stored	40 CFR 264.172	ARAR	
	• Closed during storage (except to add or remove waste)	40 CFR 264.173	ARAR	
	A container is any portable device in which a material is stored, transported, disposed of, or handled.			
	Inspect container storage areas weekly for deterioration.	40 CFR 264.174	ARAR	
	Place containers on a sloped, crack-free base, and protect from contact with accumulated liquid. Provide containment system with a capacity of 10 percent of the volume of containers of free liquids.	40 CFR 264.175	ARAR	
	Remove spilled or leaked waste in a timely manner to prevent overflow of the containment system.			
	Keep containers of ignitable or reactive waste at least 50 feet from the facility's property line.	40 CFR 264.176		
	Keep incompatible materials separate. Separate incompatible materials stored near each other by a dike or other barrier.	40 CFR 264.177	ARAR	
	At closure, remove all hazardous waste and residues from the containment system, and decontaminate or remove all containers, liners.	40 CFR 264.178	ARAR	

Table G-6
Potential Action-Specific ARARs
for the Davis Site

Action	Requirement/Prerequisite	Citation	Applicability	Comments
Treatment (miscellaneous)	Treatment of hazardous wastes in units not regulated elsewhere under RCRA (e.g., air strippers).			
	Standards for miscellaneous units (long-term retrievable storage, thermal treatment other than incinerators, open burning, open detonation, chemical, physical, and biological treatment units using other than tanks, surface impounds, or land treatment units) require new miscellaneous units to satisfy environmental performance standards by protection of groundwater, surface water, and air quality, and by limiting surface and subsurface migration.	40 CFR 264 (Subpart X)	ARAR	The substantive portions of these requirements will be applicable or relevant and appropriate to the construction, operation, maintenance, and closure of any miscellaneous treatment unit (a treatment unit that is not elsewhere regulated) constructed on the Davis Site for treatment and/or disposal of hazardous wastes.
	Treatment of wastes subject to ban on land disposal must attain achievable concentrations by best demonstrated available treatment technologies (BDAT) for each hazardous constituent in each listed waste.	40 CFR 268 (Subpart D)	ARAR	The substantive portions of these requirements are applicable to the disposal of any Davis Site wastes that can be defined as restricted hazardous wastes.
	BDAT standards are based on one of four technologies or combinations: for wastewaters (1) steam stripping; (2) biological treatment; or (3) carbon adsorption (along or in combination with (1) or (2); and for all other wastes (4) incineration. Any technology may be used, however, if it will achieve the concentrations levels specified.			The substantive portions of these requirements are relevant and appropriate to the treatment prior to and disposal of any wastes that contain components of restricted wastes in concentrations that make the site wastes sufficiently similar to the regulated wastes. The requirements specify levels of treatment that must be attained prior to land disposal.
	A miscellaneous unit shall be located, designed, constructed, operated, maintained, and closed in a manner that will ensure protection of human health and the environment. Permits for miscellaneous units shall contain terms and provisions necessary to protect human health and the environment.	22 CCR 66264.601	ARAR	The substantive portions of these requirements are applicable to construction, operation, maintenance, and closure of any miscellaneous treatment unit.
	Hazardous waste or reagents shall not cause treatment equipment to leak, corrode, or fail. Equipment shall have a means to stop continuously fed inflow. Hazardous waste must be sampled before being treated.	22 CCR Article 17, Chapter 15	ARAR	The substantive portions of this requirement are applicable to the treatment of hazardous waste by chemical, physical, or biological methods.

Table G-6
Potential Action-Specific ARARs
for the Davis Site

Action	Requirement/Prerequisite	Citation	Applicability	Comments
Waste Characterization	A person who generates a waste shall first determine if it is a waste and secondly if it is a hazardous waste according to 66261.4 and Chapter 11.	22 CCR 66262.11	ARAR	All regulations are applicable to any hazardous waste generated at the Davis Site.
Discharge of Wastewater Effluent from Treatment System	Surface discharge of treated effluent.			
	Applicable federally approved state water quality standards must be complied with. These standards may be in addition to more stringent federal standards under CWA.	40 CFR 122, 125, and 136	ARAR	Treated wastewater effluent may be used for irrigation that may runoff to local streams. Effluent quality will comply with all discharge standards.
	Applicable federal water quality criteria for the protection of aquatic life must be complied with when environmental factors are being considered.	50 FR 30784 (July 29, 1985)	ARAR	
	Regulations established by the State and Regional Water Boards to protect water quality by regulating waste disposal, including the discharge of wastewater effluent from a treatment plant, must be complied with.	California Water Code, Division 7, Section 13000 et seq.	ARAR	
	SWRCB and RWQCB water quality objectives and standards must be complied with. Beneficial uses of particular bodies of water must be protected. Standards to protect aquatic life must be met.	Inland Surface Waters Plan and the Central Valley Basin Plan	ARAR	See chemical-specific table for Inland Surface Waters Plan water quality objectives
Vadose Zone and Groundwater Treatment	Control of air emissions of volatile organics and gaseous contaminants.	40 CFR 61	ARAR	Emissions from treatment unit(s) will be controlled according to the substantive portions of these requirements.
	Standards for air emissions from treatment process vents. Control devices shall be monitored and inspected to ensure proper maintenance and operation.	40 CFR 264, Subpart AA and 22 CCR, Article 27, Chapter 15	ARAR	
	Standards for air emissions from equipment leaks. Equipment shall be designed so as to prevent leakage of organic emissions to the atmosphere.	40 CFR 264, Subpart BB and 22 CCR Article 28, Chapter 15	ARAR	
	BACT requirements and new source emission standards must be met. Opacity, nuisance, and fugitive dust control standards must be met. A nonacceptable health risk shall not be imposed.	YSAPCD Rules 3.4, 2.3, 2.5	ARAR	BACT will be applied. All reasonable precautions will be met to comply with fugitive dust and opacity standards Risk Assessment will be conducted to ensure compliance with nuisance standards.
	Cleanup values for the vadose zone and groundwater must comply with SWRCB requirements. Technical and economic feasibility will be considered.	SWRCB Resolution 68-16 SWRCB Resolution 92-49 23 CCR, Division 3, Chapter 15	ARAR TBC ARAR	

Table G-6
Potential Action-Specific ARARs
for the Davis Site

Action	Requirement/Prerequisite	Citation	Applicability	Comments
Transportation of Contaminated Materials from Treatment System (i.e., spent solvents or spent GAC).	A generator shall not treat, store, dispose of, transport, or offer for transportation, hazardous waste without having received an identification number. A generator who transports or offers for transportation, hazardous waste for offsite transfer, treatment, storage, or disposal shall prepare a manifest, DHS Form 8022A. Before transporting hazardous waste, all packaging, labeling markings and placarding shall be performed in accordance with the Department of Transportation Regulations under Title 49 CFR Part 172.	22 CCR Article 2, Chapter 12 22 CCR 66262.20 22 CCR 66262.30-33	ARAR	Wastes removed from the site for disposal (i.e., spent GAC, soil boring cuttings) will be handled in accordance with all transportation requirements.
Storage	A generator may accumulate hazardous waste onsite for 90 days without a permit provided: • The generator does not generate more than 100 kilograms of hazardous waste or one kilogram of acutely hazardous waste. • The generator does not generate more than one kilogram of extremely hazardous waste during any calendar month. A generator who accumulates waste for more than 90 days is an operator of a storage facility and is subjected to associated requirements.	22 CCR 66262.34	ARAR	Applicable to any hazardous waste stored onsite (i.e., spent solvents, spent GAC).
Leaking Underground Fuel Storage Tanks	Soil contaminated with diesel fuel from leaking underground storage tanks shall be remediated in accordance with Yolo County Health Department or RWQCB guidelines or both.	Tri-Regional Board Recommendations for Preliminary Investigation and Evaluation of Underground Tank Sites	ARAR	
Incineration	Incinerators shall not have charging rates greater than 50 tons per day. New source performance standards (NSPS) reflect the degree of emissions limitations and the percent reduction achievable through the application of the best technological system of continuous emission reduction.	40 CFR, Part 60 Subpart E	ARAR	All federal, state, and local incineration requirements are applicable if incineration is used for offgas treatment.

Table G-6
Potential Action-Specific ARARs
for the Davis Site

Action	Requirement/Prerequisite	Citation	Applicability	Comments
Incineration (continued)	Performance Standards An incinerator burning wastes shall be designed, constructed, and maintained so that it will meet the following performance standards: 1. Except for EPA Hazardous Waste No. F020, F021, F022, F023, F026, and F027, an incinerator burning waste shall achieve a destruction and removal efficiency (DRE) of 99.99 percent for each principle organic hazardous constituent (POHC). 2. An incinerator burning hazardous wastes F020, F021, F022, F023, F026, and F027 shall achieve a DRE of 99.9999 percent for each POHC. In addition, the owner or operator shall notify the Department of the intent to incinerate these wastes.	22 CCR 66264.343	ARAR	F020-Wastes of tri- or tetrachlorophenol or of intermediates. F021-Wastes of pentachlorophenol. F022-Wastes of tetra-, benta-, or hexachlorobenzenes under alkaline conditions. F023-Wastes from the production of materials on equipment previously used for the production of tri- and tetrachlorophenols. F026-Wastes from the production of materials on equipment previously used for the manufacturing use of tetra-, penta- or hexachlorobenzene under alkaline conditions. F027-Discarded, unused formulations containing tri-, tetra- or pentachlorophenol.
	Operating Requirements a. An incinerator shall be operated in accordance with operating requirements specified in the permit. b. Each set of operating requirements will specify the composition of the waste feed.	22 CCR 66264.345	ARAR	The substantive portions of this requirement are applicable.

Land Disposal Restrictions

The land disposal restrictions, 40 CFR Part 268, and the general land disposal prohibition in absence of a permit (40 CFR 270.1) will be applicable or relevant and appropriate to discharges of contaminated materials to land. The remedial alternatives presented do not include land disposal of untreated material. Untreated water and soil will remain within the CERCLA "unit."

Storage

The RCRA storage requirements, 40 CFR-264.170 to 254.178, will be applicable or relevant and appropriate to the storage of contaminated groundwater or soil.

Treatment

Soil vapor extraction units, air strippers, and the other treatment alternatives discussed in this RI/FS are miscellaneous RCRA units. Therefore, the substantive requirements of 40 CFR Subpart X, including any closure and postclosure care, will be applicable or relevant and appropriate.

Reinjection

RCRA Section 3020 is applicable or relevant and appropriate to reinjection of treated groundwater into or above a formation that contains an underground source of drinking water.

According to the RWQCB, the reinjection of trated groundwater cannot degrade the high quality of uncontaminated areas of the aquifer. Best Available Technology (BAT) must therefore be applied to bring the concentration of contaminants to below detection limits.

Closure and Postclosure

To the extent present or former RCRA units are identified in the source areas, RCRA closure and postclosure requirements may be applicable or relevant and appropriate.

A waste management unit is required by 23 CCR 2580 to be closed in accordance with an approved closure and postclosure maintenance plan. This will be necessary if wastes are to be left in place that could adversely impact groundwater quality.

Air Monitoring for Process Vents and Equipment Leaks

The requirements of 40 CFR 264, Subparts AA and BB and 22 CCR Chapter 15, Articles 27 and 28, will be applicable or relevant and appropriate.

Groundwater Monitoring and Groundwater Protection Standards

Groundwater monitoring requirements under 40 CFR 264 Subpart F are applicable if the CERCLA remedial action involves creation of a new disposal unit, when remedial actions are undertaken at existing RCRA units, or where disposal of RCRA hazardous wastes occurs as part of the remedial action.

The requirements of 40 CFR Section 264.94 establish three categories of groundwater protection standards that are potentially relevant and appropriate: background concentrations, RCRA MCLs, and Alternative Concentration Limits. The MCLs under the Safe Drinking Water Act are relevant and appropriate for the site (see Chemical-Specific ARARs, discussed above). In complying with SDWA MCLs, cleanup will also be consistent with RCRA MCLs. When no MCL has been established, a remediation level that is the equivalent of a health-based ACL under RCRA may be relevant and appropriate.

Groundwater monitoring requirements are also found in 23 CCR 2550.5. This section states that the RWQCB shall specify monitoring points at the point of compliance. The point of compliance is defined as "a vertical surface located at the hydraulically downgradient limit of the waste management unit and extends through the uppermost aquifer underlying the unit." This section is applicable to any source contamination areas.

Corrective Action

The proposed 40 CFR Subpart S corrective action regulations are TBC to land-based remedial actions undertaken at the Davis Site.

In addition to the federal requirements, 23 CCR 2550.10 requires the discharger to implement a corrective action program to remediate releases of hazardous waste. A monitoring program should be established to demonstrate the effectiveness of the corrective action. This applies to any source contamination areas.

Air Emissions Requirements

Ambient Air Quality Standards and New Source Review

Both the national (federal) and California governments have established ambient air quality standards (NAAQS and CAAQS, respectively) for a number of air pollutants, referred to as criteria pollutants. The criteria pollutants include:

- Carbon monoxide
- Lead
- Oxides of nitrogen (NO_x) as nitrogen dioxide

- Ozone (Reactive organic gases, also known as VOC, and NO_x are precursors to ozone formation)

- Particulate matter less than 10 microns in aerodynamic diameter

- Sulfur dioxide

A project cannot cause or contribute to an exceedance of the applicable NAAQS or CAAQS. To ensure this, new or modified sources of air pollutants are required to comply with new source review (NSR) regulations. Remedial actions conducted under CERCLA are required to comply with the substantive requirements of applicable rules and regulations but are not required to obtain permits. NSR regulations are promulgated and permits are issued by the local air pollution control districts in California. In the case of the Davis Site, the local regulatory agency is the Yolo/Solano Air Quality Management District (Y-S AQMD).

The Y-S AQMD has proposed changes to its current NSR rules (Rule 3.4), adopted in February 1980. The current rules require that proposed projects with net emissions increase(s) greater than 250 lb/day must provide offsets for the affected pollutant(s). Under the proposed changes, offsets would be required if the net emissions increase(s) are greater than 15 ton/year or 82 lb/day. Under the current rules, applicants are also required to apply Best Available Control Technology (BACT) to proposed projects with net emissions increase(s) greater than 250 lb/day. With proposed changes, BACT requirements would be triggered if emission increases are greater than 10 lb/day.

Other ARARs for the Davis Site include the following:

- Y-S AQMD Rule 2.3–Ringelmann Chart: No person shall discharge into the atmosphere from any single source of emissions whatsoever any air contaminant, other than uncombined water vapor, for a period or periods aggregating more than three minutes in any one hour which exceeds 20 percent in opacity or a No. 1 on the Ringelmann Chart, as published by the United States Bureau of Mines.

- Y-S AQMD Rule 2.5–Nuisance: The project should not create a public nuisance. This includes a non-acceptable health risk, excess odors, or other conditions that may result in complaints. All reasonable precautions should be taken not to cause or allow the emissions of fugitive dust from being airborne beyond the property line from which the emission originates.

- Y-S AQMD Rule 3.1–Authorizations and Permits Required: No person shall build or operate any facility or equipment which may cause the issuance of air contaminants of which may control air contaminants without obtaining authorization from Y-S AQMD. The substantive portions of this rule are applicable.

- Y-S AQMD Rule 2.13—Organic Solvents: A person shall not discharge more than 15 pounds of organics in any one day nor 3 pounds in any one hour from any equipment or machine in which any organics come into contact with flame unless the discharge has been reduced by at least 85 percent. In addition, a person shall not discharge more than 3,000 pounds of organics or 40 pounds of photochemically reactive organics in one day nor more than 450 pounds of organics or 8 pounds of photochemically reactive organics in any one hour, from any machine or equipment used for employing or applying organics, unless the discharge has been reduced by at least 85 percent.

New Source Performance Standards

The federal EPA establishes new source performance standards (NSPS). These standards reflect the degree of emission limitation and the percentage reduction achievable through the application of the best technological system of continuous emission reduction that EPA determines is adequately demonstrated for each particular source category. The only NSPS source category that might be considered applicable to the technologies being considered for the Davis site remediation is incinerators, if a thermal oxidizer is employed. The requirements found in Subpart E of 40 CFR, Part 60, are only applicable to incinerators with charging rates greater than 50 tons per day. If used at the Davis Site, a thermal oxidizer would have a charging rate far less than that regulated by the incinerator NSPS.

Requirements for Noncriteria Pollutants—Toxic Air Contaminants

In addition to the criteria pollutants discussed above, there has been increasing concern about toxic air contaminants in recent years. Toxic air contaminants (TACs) include airborne inorganic and organic compounds that can have both short-term (acute) and long-term (carcinogenic, chronic, and mutagenic) effects on human health.

Prior to the 1990 amendments to the Clean Air Act, the EPA conducted a program to establish National Emission Standards for Hazardous Air Pollutants (NESHAPs). NESHAPs were established for benzene, vinyl chloride, radionuclides, mercury, asbestos, beryllium, inorganic arsenic, radon 222, and coke oven emissions. The 1990 Clean Air Act amendments require EPA to set standards for categories and subcategories of sources that emit hazardous air pollutants, rather than for the pollutants themselves. The deadline for the first set of EPA standards is November 1994. NESHAPs set before 1991 will remain applicable.

Under Assembly Bill 1807, California has a program for identifying and developing emissions control and reduction methods for TACs. The California Air Resources Board has identified 15 compounds as TACs and is developing measures for the control of these TACs. None of the control measures developed to date for the identified TACs are applicable to the proposed remediation technologies or their emissions.

Y-S AQMD has not yet established levels of acceptable risk for use in evaluating the impacts of new and proposed projects, such as the Davis site remediation. Based on communications with the Y-S AQMD, levels currently being considered are similar to those used by the Sacramento Metropolitan Air Quality Management District (SMAQMD). SMAQMD has released a "Permit Procedure Regarding Criteria for Calculating an Excess Cancer Risk to the Public Whom May be Exposed to Carcinogenic Air Contaminants from a New/Modified Toxic Air Emission Source," September 9, 1991. This permit procedure requires screening and potentially refined risk assessment of human health effects associated with exposure to toxic air contaminants. Both residential and workplace exposures must be evaluated. Cancer risks are considered acceptable if risks do not exceed one theoretical excess lifetime cancer case per million individuals. If the applicant applies Toxic Best Available Control Technology (TBACT), risks are acceptable if they do not exceed 10 theoretical lifetime cancer cases per million individuals. The proposed remediation project may be required to conduct a risk assessment and demonstrate acceptable risks, as mentioned previously in the discussion of Y-S AQMD Rule 2.5—Nuisance.

Porter-Cologne Water Quality Control Act

The State Water Resources Control Board and the RWQCBs derive their statutes from Porter-Cologne and, as such, are responsible for the protection of existing and probable future beneficial uses of State waters. Under Porter-Cologne, the Regional Boards' objectives are achieved primarily though an ongoing basin planning program and the establishment of requirements for the discharge of waste to waters or to the land of the state where such discharge has the potential for water quality impacts. Additionally, waste discharge requirements (WDR) are written to implement regulations promulgated by the State Board in Title 23 of the CCR. The establishment of the WDRs by the State Boards may be necessary to regulate any proposed offsite discharge where CERCLA waste has been mixed with non-CERCLA waste. The substantive requirements of Porter-Cologne would also be ARARs for nonsite remedial activities. Requirements under Porter-Cologne could be chemical-specific, action-specific, and/or location-specific.

State Water Resources Control Board Resolutions

Resolution 92-49 establishes policies and procedures for the oversight of investigations and cleanup and abatement activities resulting from discharges which affect or threaten water quality. The Regional Board is authorized to "require complete cleanup of all waste discharged and restoration of affected water to background conditions (i.e., the water quality that existed before the discharge)" or the highest water quality which is reasonable if background conditions cannot be restored. Technical and economical feasibility will be considered.

According to the RWQCB, "background" is defined as 0.5 μg/l for all VOCs. Under this resolution, the contaminated groundwater at the Davis Site would need to be remediated to 0.5 μg/l. This level, as well as MCLs, has been considered in the development of extraction options.

Resolution 92-49 is currently considered a TBC because it is not a promulgated policy. For this reason, the 0.5 $\mu g/l$ cleanup criterion would be considered a remedial goal, not an enforceable remedial requirement.

Resolution 68-16 requires the continued maintenance of high quality water of the state. Unlike the federal antidegradation policy, this state policy includes groundwater as well as surface water. Water quality may not be allowed to be degraded below what is necessary to protect the "beneficial uses" of the water source. Beneficial uses of waters in the vicinity of the Davis Site are identified in the Basin Plan for the Central Valley Region.

Resolution 68-16 is an ARAR that applies most often to CERCLA cleanups that involve extracting, treating, and discharging treated groundwater. Activities that discharge to high quality waters (unaffected surface or groundwater) require the use of "best practicable treatment or control" of the discharge to avoid pollution or nuisance and maintain high quality. Best practicable treatment would take into account technical and economic feasibility. This policy also applies to vadose zone contamination because of the possibility that it may continue to degrade groundwater quality, which would not be protective of beneficial uses. The requirement to remediate soils and groundwater to background concentrations unless proven technically and economically infeasible can also be found in 23 CCR, Division 3, Chapter 15.

Waivers

CERCLA §121 provides that, under certain circumstances, an otherwise applicable or relevant and appropriate requirement may be waived. These waivers apply only to the attainment of the ARAR; other statutory requirements, such as that remedies be protective of human health and the environment, cannot be waived. The waivers provided by CERCLA §121(d)(4) are listed below.

1. Interim Remedy—The remedial action selected is only part of a total remedial action that will attain such a level or standard of control when completed.

2. Greater Risk to Human Health or the Environment—Compliance with the requirement at the site will result in greater risk to human health and the environment than alternative options.

3. Technical Impracticability—Compliance with the requirement is technically impracticable from an engineering perspective.

4. Equivalent Standard of Performance—The remedial action selected will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, criteria, or limitation through use of another method or approach.

5. Inconsistent Application of State Requirements—With respect to a state standard, requirement, criterion, or limitation; the state has not consistently applied (or demonstrated the intention to apply consistently) the standard, requirement, criterion, or limitation in similar circumstances at other remedial actions.

6. Fund Balancing—In the case of a remedial action to be undertaken solely under Section 104 using the Fund; selection of a remedial action that attains the level or standard of control in the requirement will not provide a balance between the need for protection of public health and welfare and the environment at the site under consideration, and the availability of amounts from the Fund to respond to other sites that present or may present a threat to public health or welfare or the environment, taking into consideration the relative immediacy of such threats.

Additional Legal Requirements

Two additional legal requirements may be applicable to the Davis Site, as described below. These requirements may be applicable, although they are not environmental protection standards and therefore are not ARARs.

The Occupational Safety and Health Act (29 CFR 1910.120)

The Occupational Safety and Health Act requirements for worker protection, training, and monitoring are applicable to remedial actions at the Davis Site, and will also be applicable to the operation and maintenance of any treatment facilities, containment structures, or disposal facilities remaining onsite after the remedial action is completed.

OSHA regulates exposure of workers to a variety of chemicals in the workplace, and specifies training programs, health and environmental monitoring, and emergency procedures to be implemented at facilities dealing with hazardous waste and hazardous substances.

The OSHA requirements to be implemented following site remedial actions (during long-term site maintenance) are dependent on the site remedial actions selected and the nature of the wastes or hazardous substances remaining on the site Requirements other than those for hazardous waste sites may be applicable.

Standards for Transportation of Hazardous Waste (40 CFR 263, 49 CFR)

These standards are applicable to wastes that are transported offsite. The transportation standards define the types of containers, labeling, and handling required for shipment of hazardous wastes or regulated materials over public roads or by common

carriers. If any remedial alternative includes offsite treatment or disposal wastes, treatment system effluents or residues, or other contaminated materials, these regulations will be applicable. Any action or waste management occurring offsite is subject to full regulation under federal, state, and local law.

Works Cited

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PREPARED FOR: Davis RI/FS Report

PREPARED BY: Peter Lawson/CH2M HILL, Redding

DATE: September, 9, 1993

SUBJECT: Analysis of Vadose Zone Contamination Impacts
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.13

Purpose and Scope

Field investigations have detected significant quantities of volatile organic compounds (VOCs) in shallow (5 to 20 feet) and intermediate (20 to 40 feet) soil gas samples collected at the Davis Global Communications Site (Davis Site), which is 4 miles south of the City of Davis. The purpose of this technical memorandum is to present an estimate of the long-term threat these VOCs may pose to groundwater beneath the site. Field investigation results were used as a basis to simulate the movement of VOCs through the vadose zone to groundwater over time. Groundwater dilution calculations were then performed to estimate the concentrations of VOCs that can be expected in the groundwater beneath the site because of contaminant loading from the vadose zone. In this analysis, no attempt was made to include the current levels of VOC contamination observed in the groundwater. The estimated incremental groundwater impacts described herein are solely caused by the movement of VOCs from the vadose zone.

The groundwater conditions at this site change significantly in response to seasonal variations in natural recharge and irrigation pumping. Groundwater levels in the B aquifer fluctuate by as much as 30 feet over the course of the year. This hydrologic condition produces a zone of the B aquifer (from approximately 40 to 70 feet bgs) that is periodically flushed by rising and falling groundwater levels. Because this zone is not truly unsaturated for most of the year, and liquid advection driven by fluctuating groundwater levels appears to be the dominant transport mechanism, this zone was not included in these vadose zone simulations. The results presented here reflect impacts to groundwater from contamination that resides in the permanent vadose zone from the ground surface to a depth of 40 feet.

Objectives

The main objective of these calculations is to evaluate whether a vadose zone remediation effort is warranted by the estimated future impacts on groundwater posed by VOCs currently residing in the vadose zone at the Davis Site.

Approach

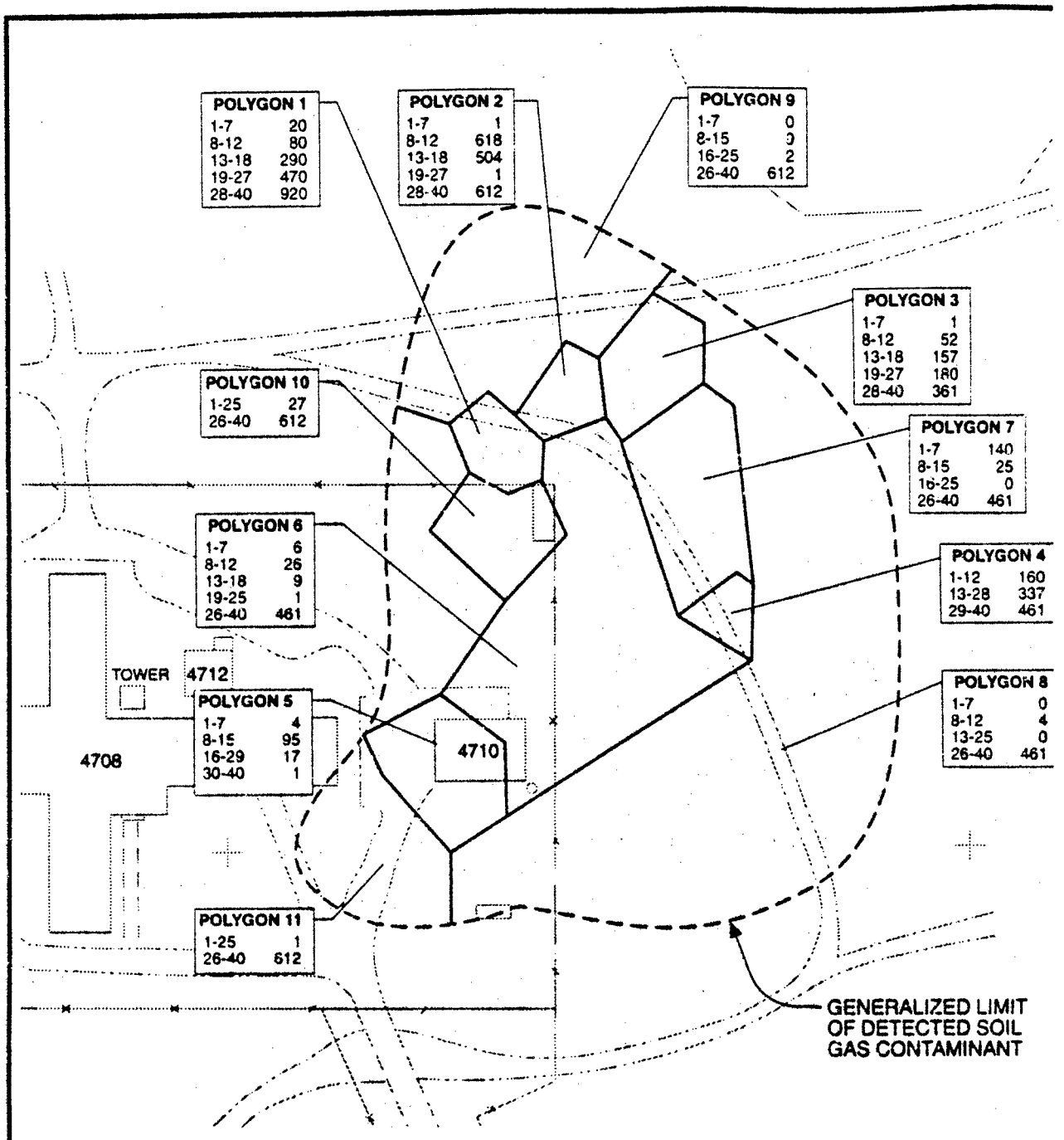
Initial Distribution of VOC Mass in the Vadose Zone

The accuracy of vadose zone transport simulations are directly dependent on an accurate estimation of the initial vertical distribution of contaminant mass in the vadose zone and on representative estimates of the soil properties through which the contaminants move. An estimate of the total mass of VOCs in the vadose zone at the Davis Site determined from measured soil gas concentrations was prepared by CH2M HILL and is included as Appendix F(b), Mass Estimate for Vadose Zone Contamination. The results of these mass estimate calculations indicate that greater than 90 percent of the vadose zone VOC contamination at the Davis Site consists of tetrachloroethene (PCE). As a result, this analysis is limited to the movement of PCE through the vadose zone and the potential impact of PCE on groundwater. Figure H-1 presents the total soil concentrations (PCE) used in this analysis. Refer to Appendix F for the details of the mass estimate calculations.

Vadose Zone Movement

The approach used to estimate groundwater impacts was to calculate the movement of the PCE through the vadose zone to the water table, and then estimate the PCE mass loading to groundwater over time. The analysis of vadose zone contaminant movement considered three phases: contaminant dissolved in the liquid phase, contaminant existing as a vapor phase in the soil atmosphere, and contaminant sorbed to the organic carbon fraction of the vadose zone soil. The transport mechanisms considered dominant in this analysis were liquid advection downward to the water table and gaseous diffusion into and out of surrounding cells driven by concentration gradients (Fick's Second Law). A one-dimensional finite difference computer model (VLEACH) was used to carry out the necessary calculations. A diagrammatic representation of the VLEACH model architecture, including all equations governing transport between phases and cells, is shown in Figure H-2. Table H-1 presents the notation used herein.

It is not practical to quantitatively consider all of the processes that may be affecting contaminant transport at the Davis Site. The following is a list of all processes incorporated in the existing VLEACH model, and several processes that were not incorporated at this time. For the processes not incorporated, an attempt was made to qualitatively describe the effect these processes may have on the natural system and our estimates.



NOTES: All PCE concentrations represent total soil concentrations.

SOURCE: Appendix F(b), Mass Estimate for Vadose Zone Contamination CH2M HILL, 1993

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FIGURE H-1
DISTRIBUTION OF PCE TOTA
SOIL CONCENTRATIONS USI
IN VLEACH SIMULATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

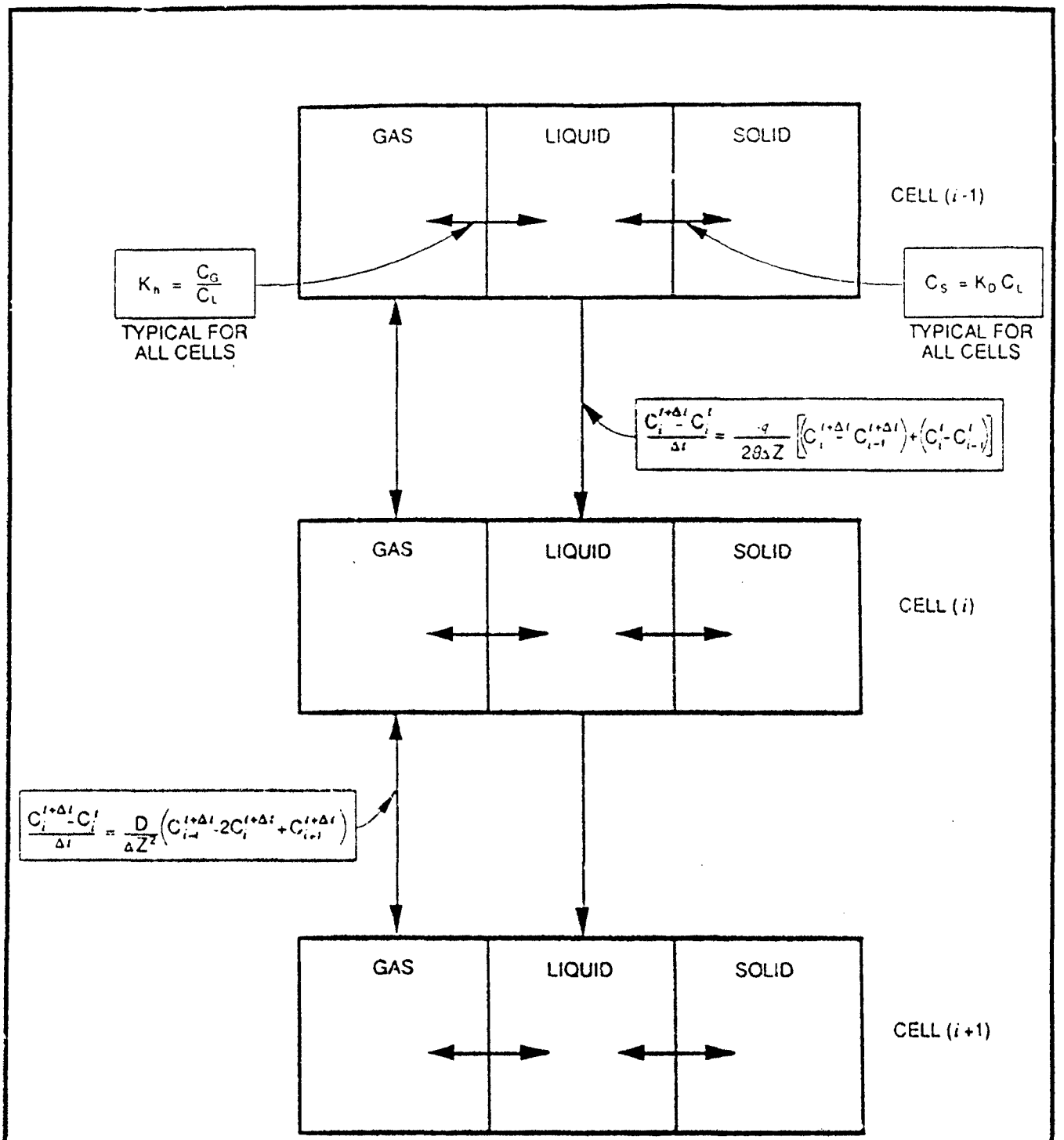

FIGURE H-2
SCHEMATIC REPRESENTATION OF VADOSE ZONE PROCESSES
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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CH2MHILL

Table H-1 Equation Variable Definitions		
M_T	=	Total mass of contamination in a model cell [M]
ΔZ	=	Thickness of cells in VLEACH calculation [L]
n	=	Total porosity of soil [dimensionless]
θ_W	=	Water-filled porosity of soil [dimensionless]
ρ_b	=	Bulk density of soil [M/L^3]
K_D	=	Distribution coefficient for soil-water partitioning [L^3/M]
K_h	=	Henry's constant for air-water partitioning [dimensionless]
C_s	=	Contaminant concentration in sorbed phase [M/M]
C_L	=	Contaminant concentration in the liquid phase [M/L^3]
C_g	=	Contaminant concentration in the gas phase [M/L^3]
f_{oc}	=	Fraction organic carbon in soil [dimensionless]
K_{oc}	=	Organic carbon partition coefficient [L^3/M]
D	=	Effective diffusion coefficient [L^2/T]
q	=	Darcian flux of percolating water [L/T]
In finite difference equations:		
$C_{i-1}^{t+\Delta t}$		
C	=	Refers to concentration of gas or liquid, depending on the equation [M/L^3]
$t+\Delta t$	=	Refers to the time step at which the concentration is calculated
i-1	=	Refers to the cell number in which the concentration is calculated

Processes Incorporated In VLEACH

Liquid Advection. Liquid advection is the process of water in the vadose zone percolating downward to the water table. In VLEACH, the only source of water to drive liquid advection is infiltration of water through the land surface. In each cell, the contaminant mass that resides in the liquid phase is redistributed according to equilibrium assumptions, and liquid with a revised contaminant concentration is transported to the cell below. The rate of advection is determined by the recharge rate and water content specified for the subarea of interest.

Gaseous Diffusion. Gaseous diffusion is the transfer of contaminant in the gas phase into adjacent cells driven by a concentration gradient. If the gas-phase contaminant concentration is higher in a given cell than it is in an adjacent cell, the contaminant will diffuse into the lower concentration cell until equilibrium is reestablished.

Sorption/Desorption. Sorption/desorption is the process by which contaminant mass is exchanged between the liquid phase and the solid phase. The magnitude of this exchange is described by a partition coefficient (K_D), which depends on the properties

of the soil, the liquid, and the specific contaminant of interest. For this application, variation of the K_D with liquid properties is not incorporated.

Volatilization. Volatilization is the process by which contaminant mass is exchanged between the gaseous phase and the liquid phase. The direction and magnitude of this exchange are estimated by an empirical constant known as Henry's constant (K_h). This constant depends on the properties of the chemical of interest.

Processes Not Incorporated In VLEACH

Preferred Pathways to Flow. The entire thickness of soil in the vadose zone is assumed to be homogeneous and to behave as a uniform porous medium. In reality, water moving in the vadose zone may follow preferred pathways. These pathways will concentrate flow in a horizontal sense, both liquid and vapor, and reduce transport times to less than those predicted from bulk soil properties. If infiltrating water follows preferential paths, some volumes of soil may not be affected by advection, and mass transfer from these soil areas will be dependent on the relatively slow process of gaseous diffusion. By assuming that these pathways do not exist, we may be underestimating the time required to move vadose zone contamination into the groundwater.

Presence of Free Product. For VLEACH calculations, it is assumed that no free product exists. Even if the solubility of a contaminant is exceeded in a model cell, no free product forms. If free product is present at the site, it may significantly increase the time required for vadose zone remediation. Density-driven flows of vapor phase would also result. The mass that resides as a free product is isolated from the equilibrium system and will only be released when the aqueous concentration drops below the solubility or the free product contacts soil vapor and directly volatilizes into the soil atmosphere.

Nonlinearity of Sorption Isotherms. One of the assumptions made was that K_D is constant. In conditions of high concentration of the selected contaminant or all contaminants present, K_D can decrease because of competition for sorption sites, and sorption may be less extensive than that predicted by the original value of K_D. This assumption overestimates the mass of contamination sorbed to the vadose zone soil and predicts a longer estimated period of vadose zone contribution of contaminant mass to groundwater.

Mineral Sorption. Use of the organic carbon partition coefficient (K_{oc}) value to estimate the K_D for trichloroethane (TCA) and dichloroethane (DCA) assumes that all sorption is onto soil organic carbon. Additional sorption onto soil minerals is also possible, but is not incorporated in the present VLEACH model.

Nonequilibrium Conditions. The present VLEACH model assumes that all processes and locations are at equilibrium.

Liquid-Phase Dispersion. Liquid-phase dispersion was neglected in this model. Dispersion can affect the arrival time of a dissolved solute front and the rate of solute removal from the vadose zone after most of the solute mass is flushed out. Since the front is assumed to have already reached the water table, dispersion will not affect the early mass loading or groundwater impacts. The peak impacts on groundwater are expected to be small. Therefore, any affect that dispersion may have on late groundwater contaminant concentrations is not critical to this investigation.

In Situ Degradation. The assumption that no in situ degradation of contamination occurs in the vadose zone is conservative. If degradation is indeed occurring, we are overestimating the mass of solvent contamination in the vadose zone.

Boundary Conditions

Upper and lower boundary conditions must be defined to run the VLEACH simulations. These boundary conditions govern the transfer of mass between the vadose zone and the atmosphere above and the water table below. These boundary conditions are described in more detail below.

Volatilization of Contamination Into the Atmosphere. The transfer of gas phase contamination from the top cell of the model into the atmosphere can be estimated by VLEACH under two different boundary conditions. The first assumes that the upper boundary is impermeable to gaseous diffusion. The second initializes the contaminant concentration in the atmosphere and estimates the vapor mass transport from the resulting concentration gradient. Since the majority of the Davis Site is unpaved and open to gaseous diffusion, an open upper boundary was selected for these simulations.

Gas Exchange Between the Lowest Cell and the Groundwater. The VLEACH model allows two options for describing the boundary condition at the base of the vadose zone. The first option is to assume that the water table is impermeable to gaseous diffusion and therefore all mass exchange into the groundwater is caused by the process of liquid advection. This option also prevents any upward movement of contaminant from the groundwater into the vadose zone. The second option is to assign a contaminant concentration for the groundwater, which remains constant throughout the simulation. Vapor transport under this boundary condition is calculated based on the concentration gradient between the gas phase concentration in the lowest cell and the vapor phase concentration that would exist in equilibrium with the specified groundwater concentration. All of our conclusions here are based on the first option, which assumes that the water table is impervious to gaseous diffusion. Laboratory experiments recently reported in the literature suggest that this is a reasonable assumption, as the capillary fringe above the water table acts as a significant barrier to gas flow (McCarthy and Johnson, 1993). Because mass transport by liquid advection is much greater than that by molecular diffusion through water, the assumption of a closed lower boundary to gas diffusion is a reasonable representation of the physical system at the site.

Description of VLEACH Calculation

This section describes the sequence of steps and equations used by the computer program VLEACH in predicting contaminant behavior in the vadose zone. It is important to note that the contaminant transport "model" is the set of governing equations presented below with the appropriate boundary conditions imposed. The computer program simply facilitates the solving of these equations in a timely fashion. Variables used in the following equations are defined in Table H-1.

Order of Calculation

Step 1—Calculate the Distribution of Contaminants Among the Three Phases. The first step is to determine the equilibrium distribution of contaminant mass in the vadose zone in the three phases (liquid, gas, and sorbed). This is done by calculating the contaminant concentration in each phase according to the following equations:

$$C_g = \frac{M_T}{\Delta Z \left[\frac{\theta_w}{K_h} + (n-\theta_w) + \rho_b \left(\frac{K_D}{K_h}\right)\right]} \quad [1]$$

$$C_L = \frac{M_T}{\Delta Z \left[\theta_w + (n-\theta_w)K_h + \rho_b K_D\right]} \quad [2]$$

$$C_s = \frac{M_T}{\Delta Z \left[\frac{\theta_w}{K_D} + (n-\theta_w)\frac{K_h}{K_D} + \rho_b\right]} \quad [3]$$

Step 2—Advective Transport of Liquid. The rate of advection is dependent upon the recharge rate defined for the polygon of interest. Cells gain water from the adjacent cell above and lose water to the cell below. The mass moving from cell to cell via advection is determined by the concentration of contaminant in the liquid residing in the cells.

Step 3—Diffusive Transport of Gas. The contaminant in the vapor phase moves into or out of adjacent cells in response to vapor concentration gradients that exist between the cell of interest and adjacent cells.

Step 4—Recalculate Total Mass in Each Cell. After this exchange of vapor and liquid between cells, the total mass in each cell is recalculated according to the following equation:

$$M_T = \Delta Z \left[\theta_w C_L + (n-\theta_w)\, C_g + \rho_b C_s\right] \quad [4]$$

Following this step, the total mass is redistributed into the three phases as described in Step 1.

Partitioning

Partitioning of contamination between the liquid phase and the organic carbon fraction of the soil is assumed to be a linear relationship according to the following equation:

$$K_D = f_{oc}\ K_{oc} \qquad [5]$$

The partition coefficient (K_D) can also be defined as:

$$K_D = \frac{C_s}{C_L} \qquad [6]$$

Exchange of contaminant between the vapor phase and the liquid phase is also linear:

$$K_h = \frac{C_g}{C_L} \qquad [7]$$

Advective and Diffusive Transport

The processes of advection and vapor diffusion are described by the partial differential equations (PDEs) presented below.

For advection: $$\frac{\partial C_L}{\partial t} = \frac{-q}{\theta}\ \frac{\partial C_L}{\partial z} \qquad [8]$$

For diffusion: $$\frac{\partial C_g}{\partial t} = D\ \frac{\partial^2 C_g}{\partial z^2} \qquad [9]$$

The approximate solutions to both of these PDEs are arrived at in a similar manner. For brevity, only the advection case will be described here. First, the PDE is approximated with a finite difference equation (FDE) of the form:

$$\frac{C_i^{t+\Delta t} - C_i^t}{\Delta t} = \frac{-q}{2\theta\Delta Z}\ \left(\left[C_i^{t+\Delta t} - C_{i-1}^{t+\Delta t} \right] + \left[C_i^t - C_{i-1}^t \right] \right) \qquad [10]$$

In this equation, the concentrations are averaged over Time Steps t and $t+\Delta t$. This gives a value of concentration in the pore water between time steps, the time at which the advection calculation is actually taking place.

If this equation is applied to each cell in the simulation, the result is a set of simultaneous equations that are most readily solved in matrix form. The program VLEACH

converts the set of equations to matrix form and solves the equations using matrix mathematics. An upper boundary condition is necessary for the top cell of the simulation because the term C_{i-1} becomes C_0, which is undefined in the model. The concentration used here is the contaminant concentration in the infiltration water, which is zero.

Results Of VLEACH Calculation

The VLEACH model allows the use of only one vertical contaminant distribution per site polygon. Since the distribution of contamination varies at different locations across the Davis Site, the site area was divided into 11 polygons with similar contaminant distributions. These polygons are identical to those used in the mass estimation procedure (Appendix F(b)) and are shown on Figure H-1.

In addition to an estimate of the initial vertical distribution of contamination for each polygon, VLEACH also requires estimates of the chemical properties of the contaminant of concern and an estimate of the properties of the soil through which the contaminant moves. Table H-2 presents estimates of the transport properties of PCE used in the VLEACH simulations, and Table H-3 presents the assumed soil properties at the site. The references for the PCE chemical properties are included in Table H-2, while the soil property estimates are based on laboratory testing of soil samples collected during drilling onsite.

The output from the VLEACH program includes an estimate of the mass loading of PCE to groundwater over time. Figure H-3 presents the total mass loading to groundwater from all site polygons over time. It is apparent from this figure that the initial mass loading rate is approximately 450 g/yr of PCE, and this rate declines continuously over the 200-year simulation. This pattern of mass loading is a result of the fact that the majority of the contaminant mass at the Davis Site resides at depths near the water table. This mass distribution eliminates any lag time that may occur as contaminants travel through the vadose zone before impacting groundwater.

Table H-2
Tetrachloroethene Chemical Properties

Property	Concentration
Aqueous Solubility (mg/l)[a]	150
Octanol/Water Partition Coefficient[b]	364
Henry's Constant (dimensionless)[b]	0.545
Free Air Diffusion Coefficient (m^2/day)[c]	0.756

[a]Arthur D. Little, Inc., 1985.
[b]Schwille, 1988.
[c]McCoy and Associates, 1986.

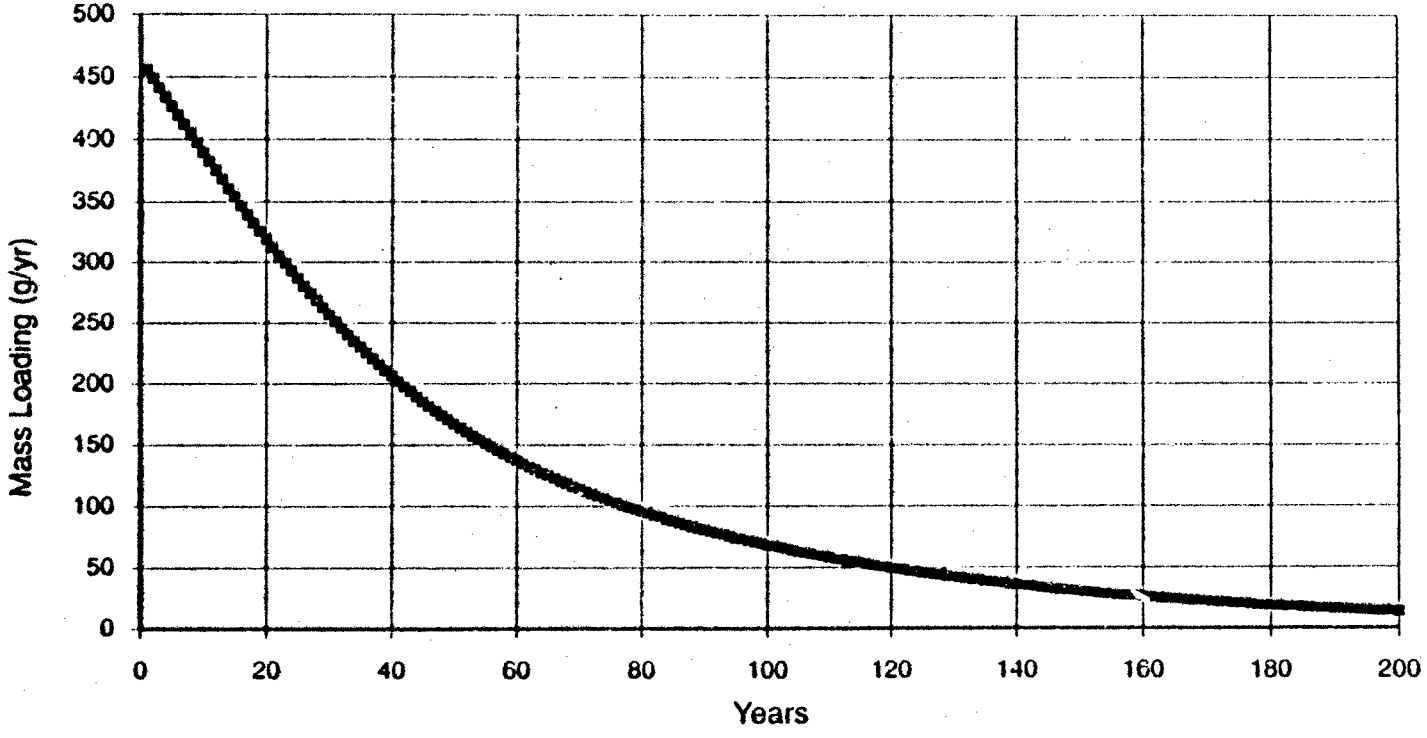

FIGURE H-3
PCE MASS LOADING
TO GROUNDWATER
DAVIS GLOBAL COMMUNICATIONS SITE

Table H-3 Assumed Davis Site Soil and Climatic Properties	
Bulk Density (g/cm^3)	1.4
Fraction Organic Carbon	0.002
Total Porosity	0.4
Volumetric Water Content	0.2
Recharge Rate (in./yr)	2.9

Groundwater Impact Calculation

The impact of PCE residing in the vadose zone or groundwater was estimated using a simple mixing cell model. Estimates of annual groundwater underflow beneath the site were calculated using Darcy's Law and the parameters listed in Table H-4. There is significant uncertainty at this site as to the thickness of aquifer in which vadose zone contamination mixes with native groundwater. The lack of a distinct, continuous aquitard between the B aquifer and C aquifer, along with the similarity in groundwater levels in these two units, suggest that they are at least partially hydraulically connected. To address this uncertainty, calculations were performed for both mixing in the B aquifer and the combined B-C aquifer so that the affects of either scenario could be examined. The method used to estimate groundwater contaminant concentrations is described in more detail in the following paragraphs.

The annual mass loading of PCE to the groundwater was obtained from the VLEACH calculation. The groundwater PCE concentrations through time were calculated using the following steps:

- **Step 1**—Initialize groundwater concentration in the mixing cell. It was assumed that the initial concentration of PCE in the mixing cell was zero.

- **Step 2**—Calculate mass leaving mixing cell during current time step:

$$M_{OUT} = Q_{OUT} \; C_{CELL}$$

where: M_{OUT} is the solvent mass leaving the mixing cell, Q_{OUT} is the annual flow rate out of the mixing cell, and C_{CELL} is the groundwater solvent concentration in the mixing cell during the current time step.

- **Step 3**—Calculate new mixing cell groundwater solvent concentration:

$$C_{CELL} = \frac{M_{IN} - M_{OUT}}{V_{CELL}}$$

where: M_{IN} is the solvent mass entering the mixing cell from solvent transport through the vadose zone, V_{CELL} is the total water volume of the mixing cell, and M_{OUT} and C_{CELL} are defined as above.

- **Step 4**—Return to Step 2 and repeat for successive time steps.

Table H-4
Aquifer Parameters

Hydraulic Conductivity of B Aquifer (ft/day)	10
Hydraulic Conductivity of B-C Aquifer (ft/day)	65
Transmissivity of B Aquifer (ft^2/day)	200 to 600
Transmissivity of B-C Aquifer (ft^2/day)	1,300
Porosity	0.4
Hydraulic Gradient (winter) (ft/ft)	0.001
Hydraulic Gradient (summer) (ft/ft)	0.005
Flow Field Width (ft)	400

Figure H-4 presents the estimated incremental impacts on groundwater caused by PCE contamination in the vadose zone. Results suggest that if contamination mixes in the B aquifer only, PCE concentrations in groundwater will reach a maximum of approximately 82 μg/l after about 30 years. If the PCE mass mixes completely in the combined B-C aquifer, PCE concentrations will reach a maximum of approximately 21 μg/l in approximately 15 years. Lower groundwater concentrations are expected with complete mixing in the combined B-C aquifer because of greater dilution of identical mass loading rates.

Sensitivity Analysis

Many assumptions were made in the course of this analysis regarding the distribution of contaminants at the Davis Site as well as the hydrogeologic framework through which they move. While the transport properties of particular contaminants are fairly well quantified, significant uncertainty exists in the magnitude and spatial variability of the properties of the sediments at the site. Because variability in these properties can significantly affect contaminant transport behavior, sensitivity analyses were performed to investigate the effects of varying hydraulic conductivity and fraction organic carbon on mass loading rates. The results of these simulations are discussed below.

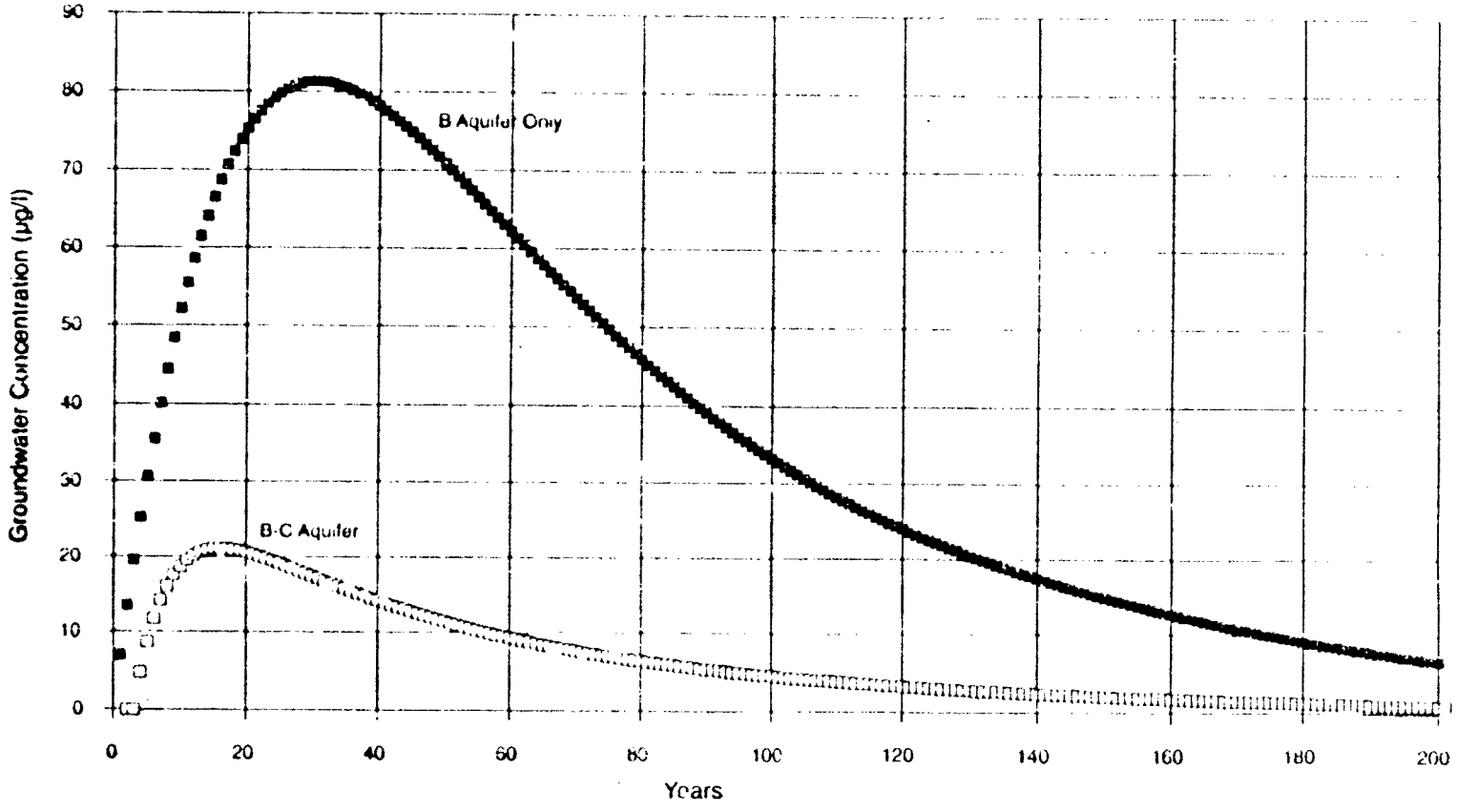

FIGURE H-4
PCE IMPACTS TO GROUNDWATER FROM VADOSE ZONE CONTAMINATION
DAVIS GLOBAL COMMUNICATIONS SITE
MCCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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CH2HILL

Hydraulic Conductivity

Figure H-5 presents the results of the sensitivity analysis on aquifer hydraulic conductivity. Since the magnitude of the aquifer hydraulic conductivity does not significantly influence the rate of water movement under unsaturated flow conditions, the primary effect this parameter has on groundwater concentrations is to vary the magnitude of dilution caused by groundwater underflow. The middle curve shown on Figure H-4 is identical to the combined B-C aquifer groundwater concentration curve presented in Figure H-3. Results of this analysis suggest that if the hydraulic conductivity is doubled, the peak groundwater PCE concentration drops to about 12 μg/l. If the assumed hydraulic conductivity is cut by half, the peak groundwater PCE concentration increases to about 37 μg/l.

Fraction Organic Carbon

Another soil property that can significantly affect contaminant movement in the vadose zone is the quantity of organic carbon that exists in the soil. The greater the quantity of organic matter present, the greater the mass of contamination that is adsorbed to soil surfaces. This process will act to retard the movement of contaminants through the vadose zone and may significantly increase the length of time over which the vadose zone continues to contribute contaminant mass to groundwater. This affect can be observed in Figure H-6. As before, the middle curve is identical to the combined B-C aquifer groundwater contamination curve presented in Figure H-3. At lower fraction organic carbon (f_{oc}) levels in the soil, the contaminants flush through the vadose zone more rapidly, producing higher initial contaminant concentrations in groundwater. At higher f_{oc} levels, the movements of contaminants through the vadose zone are retarded, and groundwater contaminant concentrations build more slowly. The opposite effects are seen in the groundwater concentration decay portion of the curves. High f_{oc} levels produce a lower peak groundwater concentration, but contaminant loading persists longer into the future. Low f_{oc} levels produce the opposite effect with a higher peak groundwater concentration and a shorter duration of mass loading to groundwater. For the magnitude of contaminant concentrations and f_{oc} levels that exist at the Davis Site, this parameter varies the estimated peak groundwater PCE concentrations produced by mass loading from the vadose zone by approximately 15 μg/l (17 μg/l to 32 μg/l).

Conclusions

The results of the analysis suggest that the mass of VOC contamination that exists in the vadose zone at the Davis Site is a significant long-term threat to groundwater quality. The PCE concentrations estimated are significantly above the State of California maximum contaminant level (MCL) set for PCE (5 μg/l). Results also indicate that the groundwater contaminant concentrations will remain above MCLs for a minimum of 10 to 15 years because of the continued movement of VOC contamination from the vadose zone to groundwater.

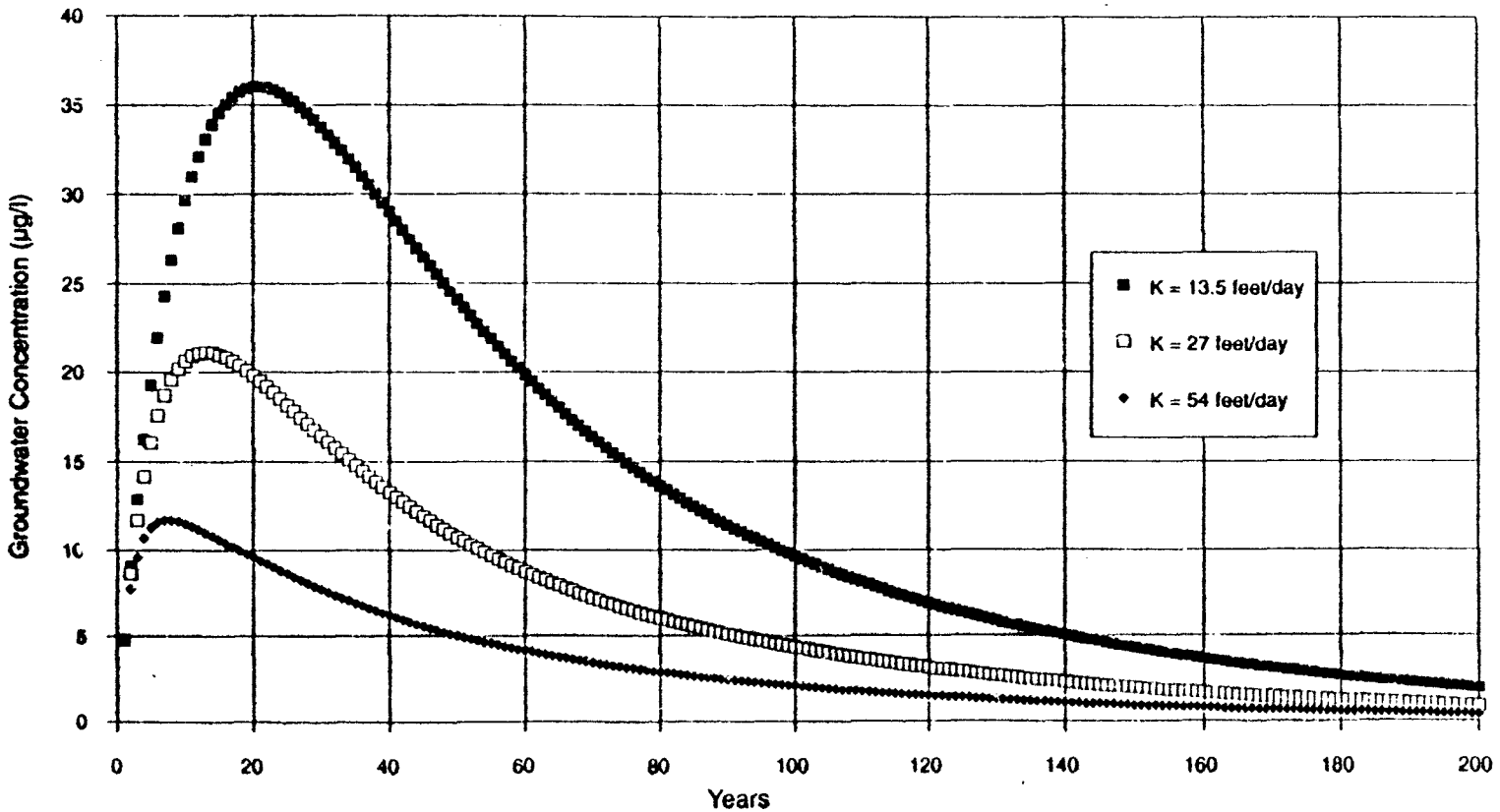

FIGURE H-5
EFFECTS OF AQUIFER HYDRAULIC CONDUCTIVITY ON GROUNDWATER IMPACTS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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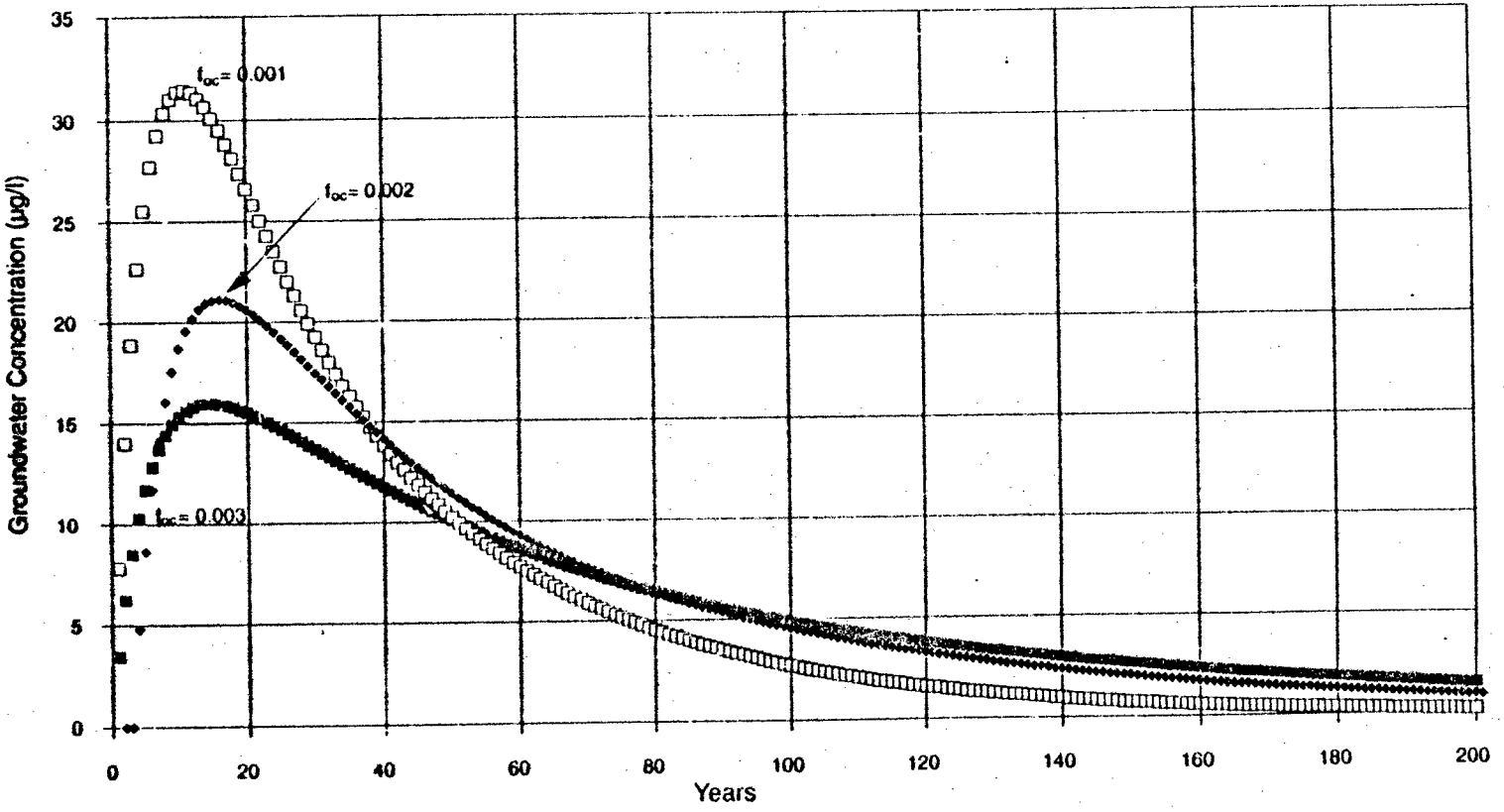

FIGURE H-6
PCE IMPACTS TO GROUNDWATER
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE

Works Cited

Arthur D. Little, Inc. 1985. *The Installation Restoration Program Toxicology Guide.* Arthur D. Little, Inc., Acorn Park, Cambridge, MA. Vols. 1, 2, 3, and 4.

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McCoy and Associates. 1986. *Determining the Distribution of Organic Contaminants Between Air, Water, and Soil.* The Hazardous Waste Consultant, Vol. 4, Issue 1, January/February.

Schwille, F. 1988. *Dense Chlorinated Solvents.* Lewis Publishers.

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Fritz Carlson/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Analysis of Soil Vapor Extraction
Davis Global Communications Site
Delivery Order No. 5022

PROJECT: SAC28722.55.18

Purpose and Scope

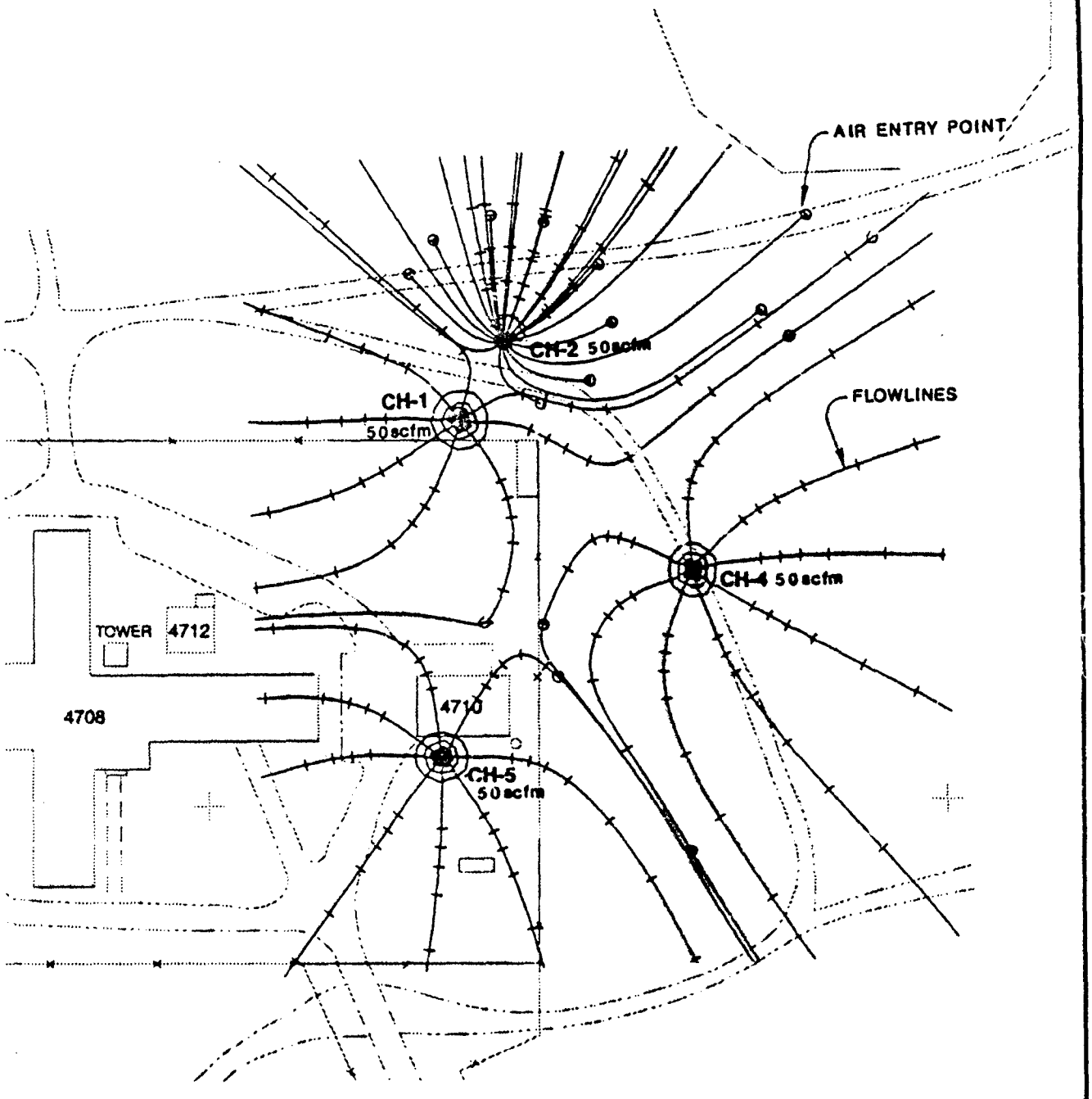
The purpose of this technical memorandum is to set forth the approach, results, and limitations of modeling of airflow in the vadose zone at the Davis Global Communications Site (Davis Site).

The objective of the modeling was to evaluate the pumping rate and well locations that would be needed to capture contaminants that exist within the vadose zone target area at the site. The target area is shown in Figure I-1. For the purpose of this technical memorandum, it is assumed that the bottom of the zone to be remediated is at a depth of approximately 40 feet; therefore, the interval that is between 40 feet and the seasonal water table is not addressed in this evaluation.

Modeling Approach

The approach to estimating the flow rates and extraction well locations was based on the assumptions presented in Massmann, 1989. The most significant assumption in this paper is that reliable predictions of the drawdown and flow pattern in a soil vapor extraction well field can be modeled using techniques for saturated zone groundwater modeling with appropriate adjustments for the lower density and viscosity of air compared with water.

The modeling code that was used is MicroFem, a finite element code developed by Hemker, et al. (1987, 1992). MicroFem can handle up to 4,000 nodes and four layers. A recent enhancement of the MicroFem code allows modeling of transient as well as steady-state conditions. For the application at the Davis Site, a two-layer steady-state model was used.



LEGEND

- GROUNDWATER MONITORING WELL
- -1- CONTOUR INTERVAL = .5 FT
- TICKMARK REPRESENTS TRAVEL TIME ON A LOGARITHMIC SCALE (successive tickmarks represent 3.6, 9, 18, 36, 91, 182, 365 days, etc.)

N

SCALE (Approximate)

0 100 FEET

FIGURE I-1
AIRFLOW PATHS DURING SVE OPERATION
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

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The assumed properties of the vadose zone that control the movement of air are based on the results of air permeability testing conducted at the site. These values are shown in Table I-1.

Table I-1
Vadose Zone Properties Used in Modeling

Vadose Zone Property	Value
Air transmissivity of the upper permeable zone (ft^2/day)	160
Air transmissivity of the lower permeable zone (ft^2/day)	4.5
Vertical resistance of the upper confining layer (day)	120
Vertical resistance of the layer separating the upper and lower permeable zones (day)	18

Modeling Results

The results of the soil vapor modeling show that the entire target area for the vadose zone can be captured by pumping 50 cfm for each of the existing wells CH-1, CH-2, CH-4, and CH-5. Flow lines to the wells are shown in Figure I-1. On the basis of travel time for air through the vadose zone to the extraction wells, the average time of travel is about 30 days.

The time required to flush the contaminants from the vadose zone within the target area cannot be accurately predicted because local heterogeneities and contaminant sorption will likely result in an extended period of contaminant release. For the purpose of estimating the time required, it should be assumed that 1,000 pore volumes need to be extracted from the vadose zone. This would mean that the vadose zone extraction system would have to be pumped for about 10 years.

Limitations of Modeling

The results of the model indicate that the vadose zone target area can be captured by pumping a total of 200 cfm from four wells. However, there may be areas within the capture zone where the properties of the strata depart from the values assumed in the model. Such heterogeneities, if present, could result in departures from the estimated flow rates and number of wells to achieve capture. In addition, the air permeability of the subsurface is likely not steady in time because of seasonal changes in water content of the unsaturated sediments. During wet seasons, the yield of the extraction wells may decrease because of lowered permeability.

The limitations of the modeling call for careful monitoring of system operation, especially during the first few years of operation.

Soil Vapor Extraction System Layout and Costs

Capital and operation and maintenance costs of the proposed system are summarized in Table I-2. The costs include materials plus associated installation, labor, operation and maintenance, and power.

Figure I-2 is a schematic of the manifold piping necessary to connect the four extraction wells and route the offgas to a centralized offgas treatment facility. A centralized blower station is proposed to supply the vacuum needed to extract vapor from the extraction wells. Two 2-hp explosion-proof blowers capable of pulling 100 scfm each would be used in the blower station. A single air/water separator would also be housed at the blower station to remove water from the airstream before entering the suction of the blower.

Table I-2
SVE System Costs

Item	Cost ($)
Capital Outlays	
Pipes and Valves	14,500
Blowers with Controls	9,000
Air/Water Separator	400
Blower Shed	3,000
Electrical	4,000
Contractor Labor	18,000
Mobilization/Demobilization	10,000
Startup	8,000
Total Capital	66,900
Annual Costs	
Power	2,000/yr
O&M (30% of Capital)	20,100

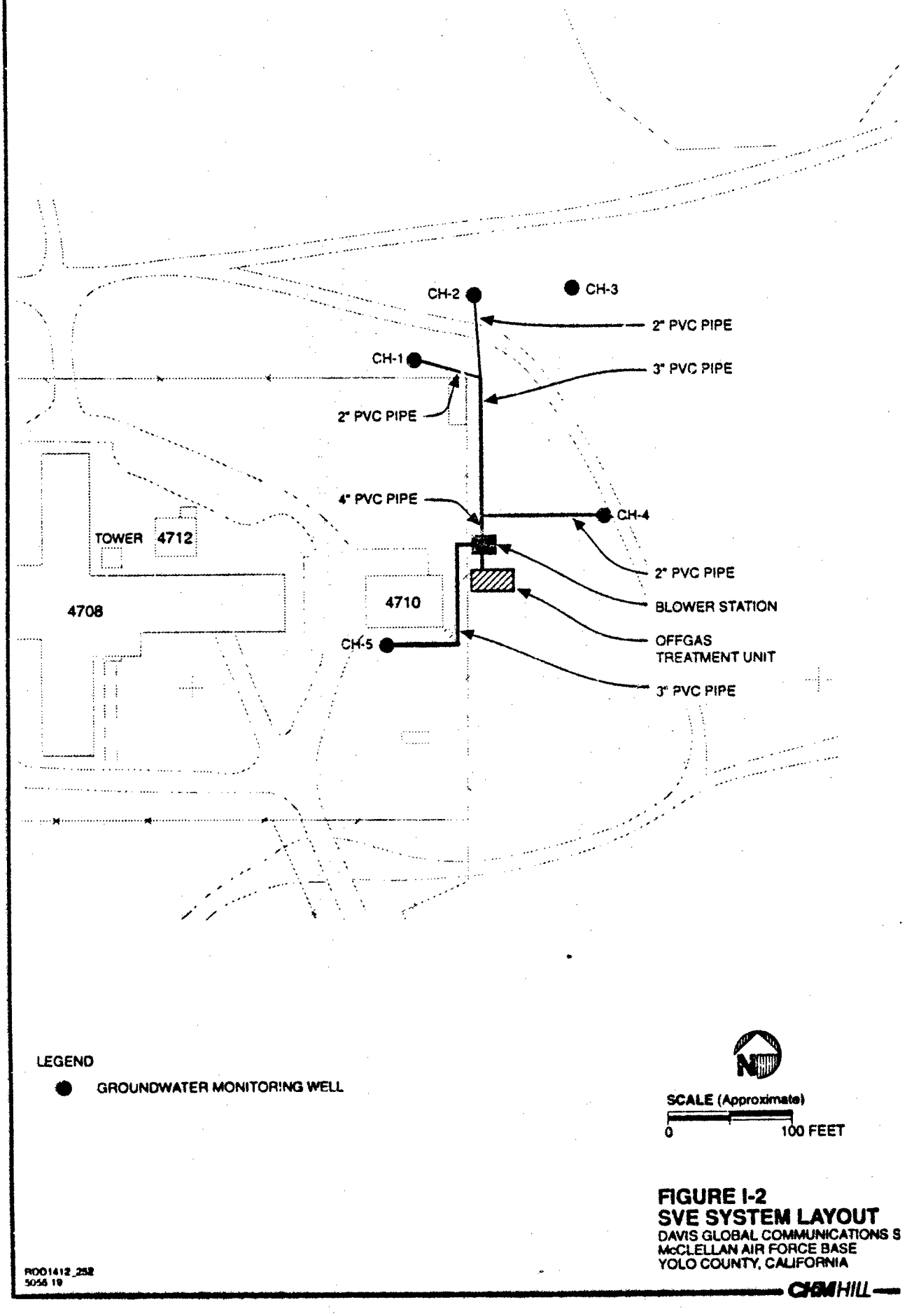

FIGURE I-2
SVE SYSTEM LAYOUT
DAVIS GLOBAL COMMUNICATIONS S
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

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Applicability of Standard Soil Vapor Extraction to the Zone of Seasonal Water Table Fluctuation

The SVE assessment discussed in this appendix only included soils down to a depth of 40 feet. The zone of seasonal water table fluctuation located from 40 to 70 feet below ground surface was not included in the assessment for two reasons:

- Recent water level data indicate that the zone is below the water table for approximately one-half of the year. Standard SVE can do nothing to address the contamination while it is submerged.

- Soils within the zone are primarily fine-grained and will likely retain a high water saturation percentage even after the water table recedes. The combination of fine-grained soils with high water saturation creates a low in situ air permeability that makes effective implementation of SVE difficult.

For these two reasons, standard SVE is not at this time thought to be a viable remediation method for the 40 to 70 feet below ground surface zone. A variation on SVE, called dual-phase extraction, should be considered for this zone, as described in Appendix O.

Works Cited

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PREPARED FOR: Davis RI/FS Report

PREPARED BY: Gerald Vogt/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Groundwater Extraction Evaluation
Davis Global Communications Site
Delivery Order 5055

PROJECT: SAC28722.55.13

Purpose and Scope

This technical memorandum summarizes the data evaluation performed to estimate the amount of groundwater extraction required for containing and removing groundwater contamination within identified target areas beneath the Davis Global Communications site (the Davis Site). The groundwater in the vicinity of the fenced main compound area at the site is contaminated with trichloroethene (TCE), tetrachloroethene (PCE), and other chlorinated volatile organic compounds (VOCs). In addition, petroleum and VOC contamination has been identified in the soil to a depth of 65 feet below land surface in the same area. This technical memorandum provides supplemental information for the Remedial Investigation/Feasibility Study Report and is based on a similar technical memorandum produced for the Intermediate Remedial Design Report (IRDR) (CH2M HILL, May 1993). The scope of this report addresses the following:

- Target areas for capturing contaminated groundwater
- Number and location of extraction wells
- Extraction rates
- Extraction and monitoring well construction
- Estimated concentrations of VOC and metals in extracted groundwater

The data analysis involved reviewing available regional and site-specific groundwater data, identifying the target areas for remediation, and performing a groundwater capture zone evaluation using a groundwater flow model. Results of these data evaluations are provided below.

Data Review

Regional Groundwater Hydrology

Figure J-1 is a contour map of groundwater elevations measured in privately-owned wells in the fall of 1990. This time period represents a relatively low water level period due to the drought and pumping during the summertime for irrigation. The figure shows that the regional groundwater flow direction is to the east toward the Sacramento River. Putah Creek, located approximately 1.5 miles north of the Davis Site, discharges to the Yolo Bypass area. The Yolo Bypass area to the east of the site appears to be a groundwater discharge area. Groundwater movement is usually upward from deeper aquifers to shallow aquifers in groundwater discharge zones.

Groundwater levels in the vicinity of the site vary seasonally due to agricultural pumping. Lands surrounding the site are used for agriculture, and the only water supply for these lands is groundwater. Water levels usually decline in the summertime irrigation season (April to September) and rise during the wintertime (October to March). The water levels can range from 30 to 65 feet in one year.

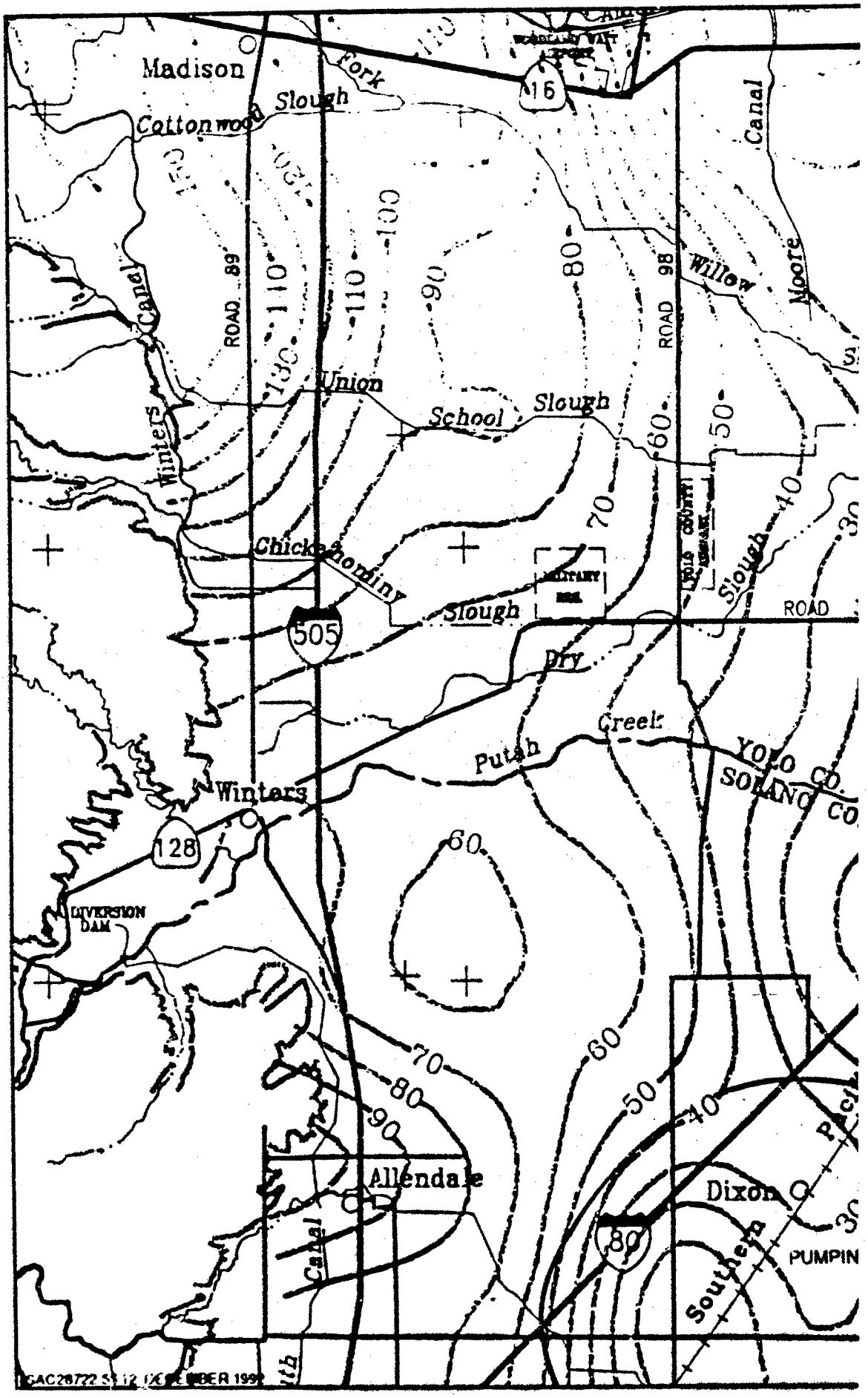
Most agricultural wells pump from depths of approximately 150 to 300 feet below land surface (bls). These wells correspond to the D and E aquifers at the site.

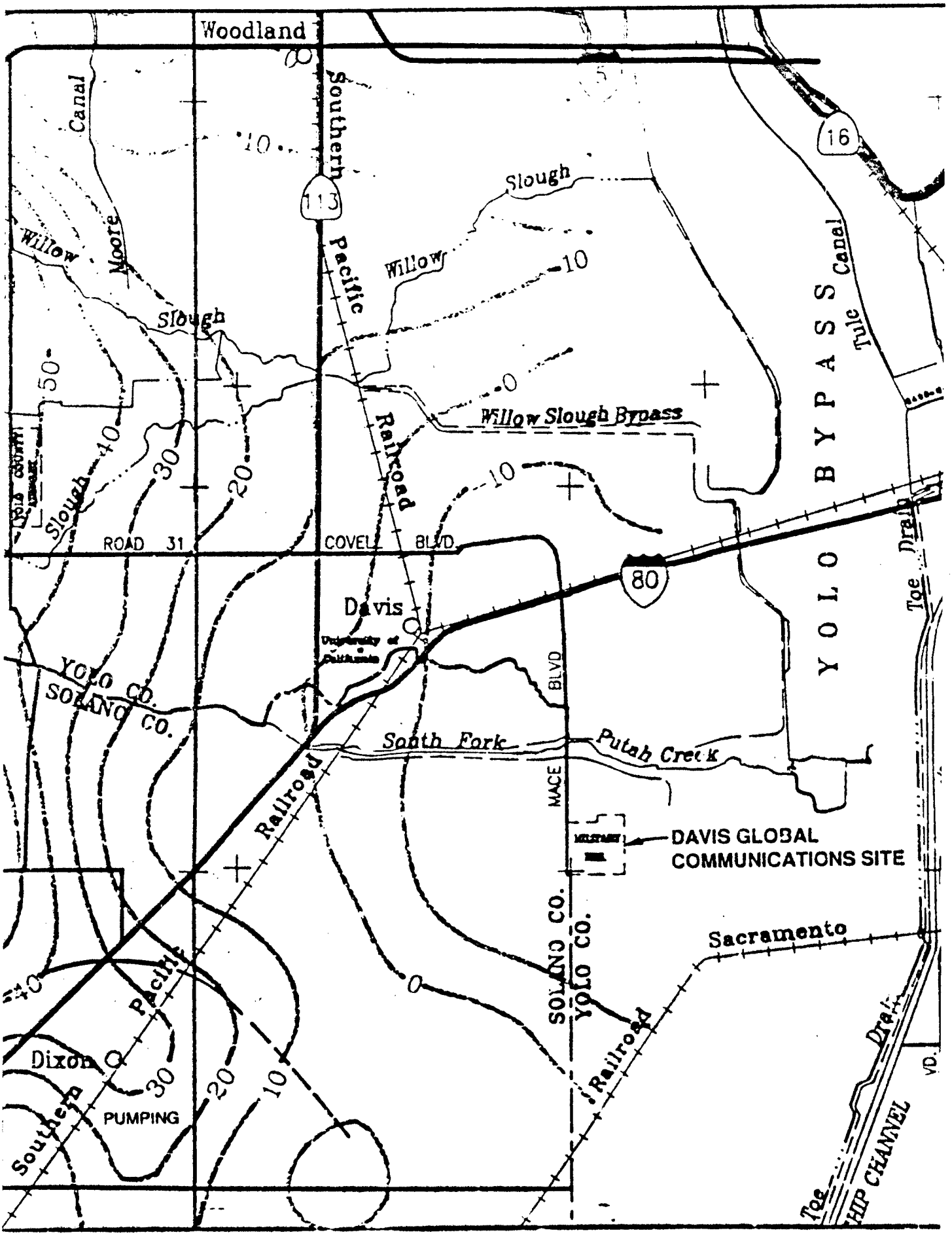
Site-Specific Groundwater

Thirty-six monitoring wells, two piezometers, and four extraction wells have been installed at the site since 1987. The well locations and site layout are shown in Figure J-2. Several aquifers have been identified on the basis of hydrogeologic and geophysical data collected while installing these wells. These aquifers, B through E, represent preferential pathways or coarser-grained layers for groundwater flow. The estimated extent of coarse-grained units is presented in cross sections in Chapter 4 of the RI/FS Report.

A generalized conceptual model of the subsurface is shown in Figure J-3. The model is based on results of five aquifer tests and on available hydrogeologic data. CH2M HILL performed three aquifer tests in C aquifer wells (MWC-3, MWC-12, and MWC-14) in August 1992 (CH2M HILL, October 1992). Aquifer tests were also performed at Well MWD-12 and MW-3 in January 1993 (CH2M HILL, March 1993). The conceptual model incorporates heterogeneities in the transmissivity of the B and C aquifers derived from the varying thicknesses of coarse-grained materials in each aquifer. The approach used to define the transmissivity distributions is presented in the Capture Zone Evaluation Section.

Figure J-4 shows water levels measured at Monitoring Well Cluster 3 from June 1992 to July 1993. This cluster was chosen because it had the most data available. Water levels measured in the B and C aquifers are typically within 0.05 foot from one


Madison
Cottonwood Slough
Canal
ROAD 89
ROAD 98
Willow
Moore
Union School Slough
Winters
Chickahominy Slough
505
Dry Creek
Putah
Winters
YOLO CO.
SOLANO CO.
128
DIVERSION DAM
Allendale
Dixon
80
Southern
PUMPIN
110
100
90
80
70
60
50
40
30



Woodland
Southern Pacific Railroad
Canal
Moore
Willow
Slough
Willow Slough Bypass
Tule Canal
YOLO BYPASS
Toe Drain
ROAD 31
COVELL BLVD.
Davis
University of California
YOLO CO.
SOLANO CO.
South Fork Putah Creek
MACE BLVD
DAVIS GLOBAL COMMUNICATIONS SITE
Sacramento
Dixon
PUMPING
Southern Pacific Railroad
SOLANO CO.
YOLO CO.
Toe Drain
SHIP CHANNEL
113
16
80

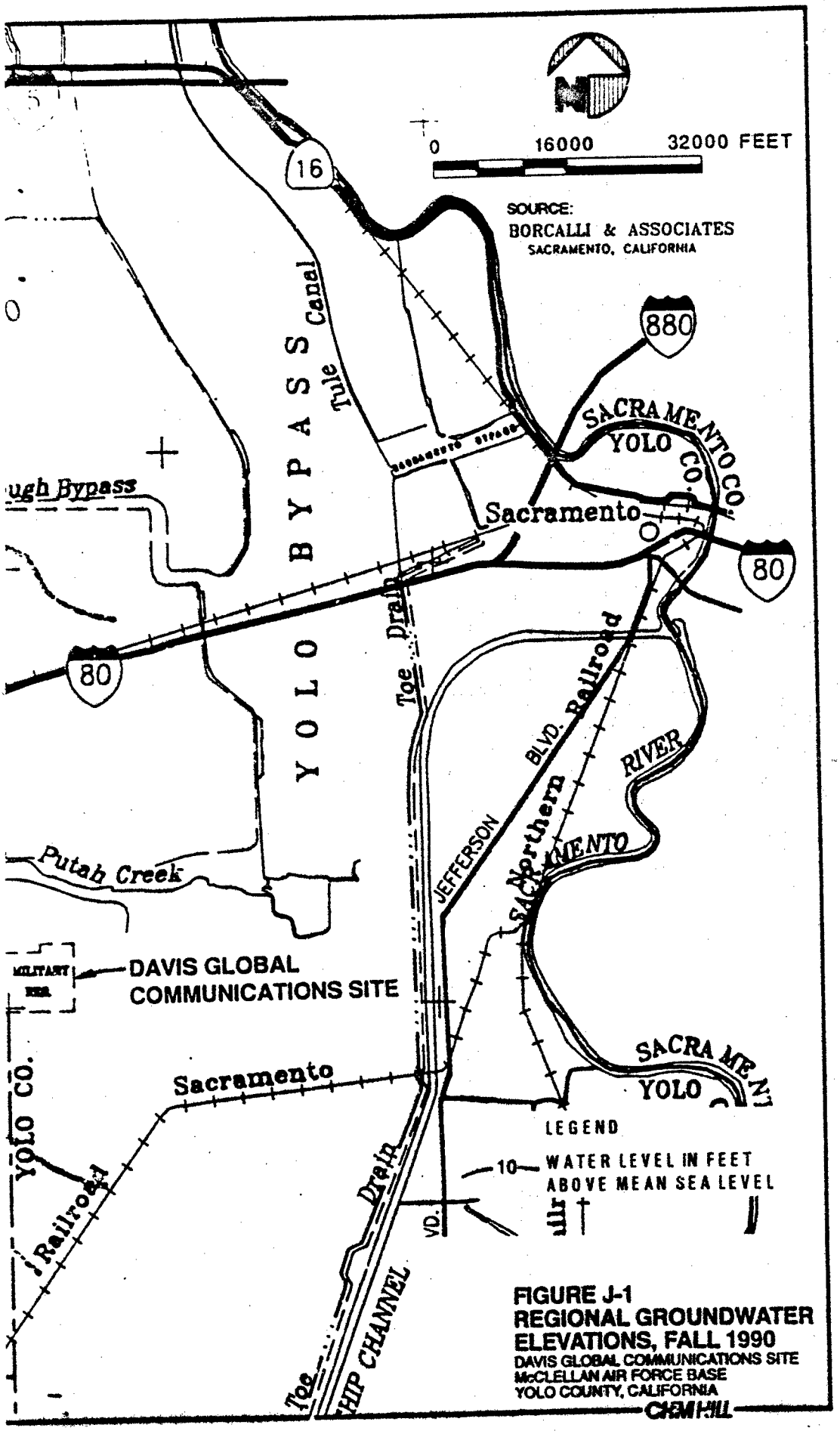
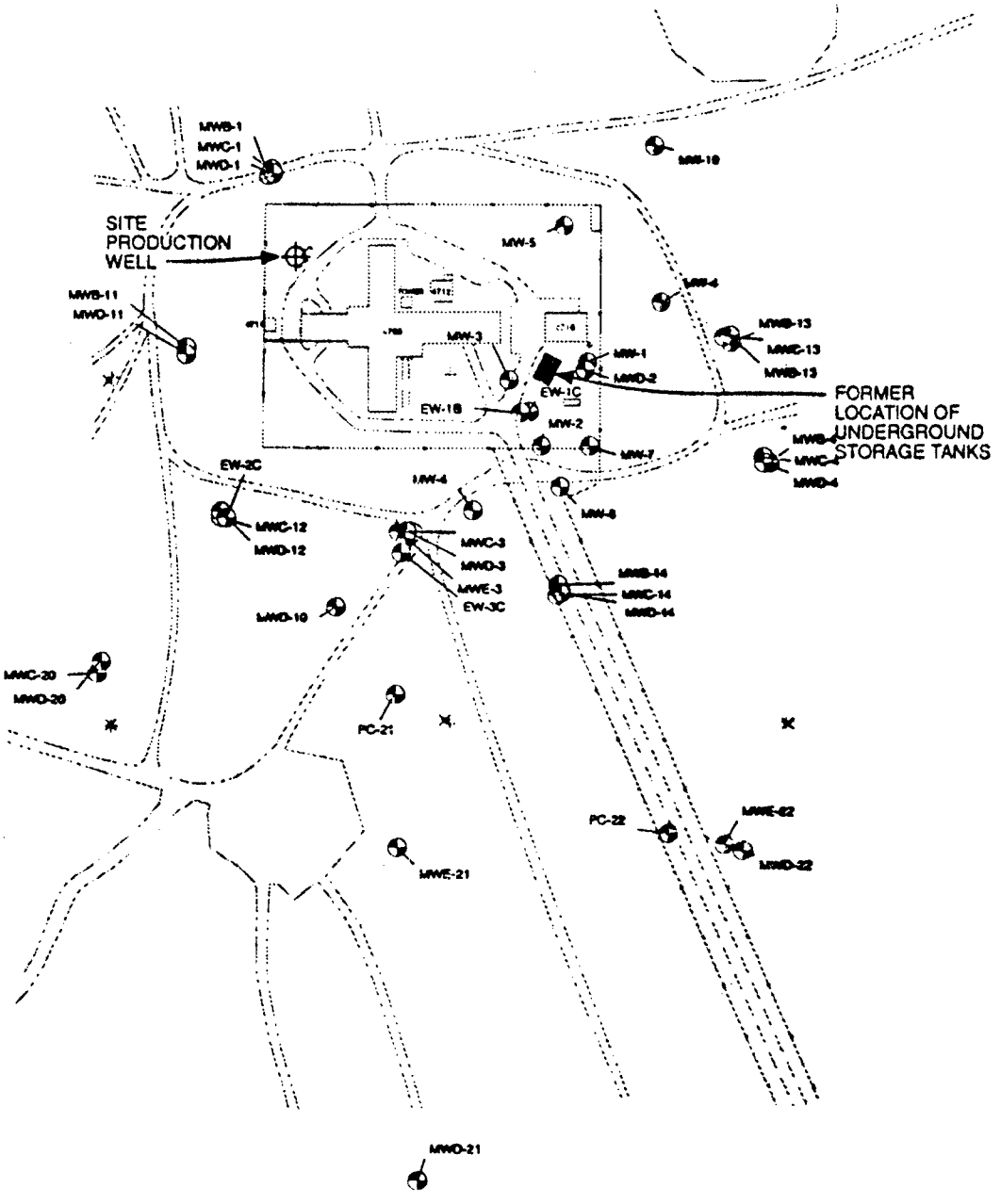


FIGURE J-1
REGIONAL GROUNDWATER ELEVATIONS, FALL 1990
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA



LEGEND

GROUNDWATER MONITORING WELL

N

SCALE (Approximate)

0 250 FEET

FIGURE J-2
SITE BASE MAP
DAVIS GLOBAL COMMUNICATIONS
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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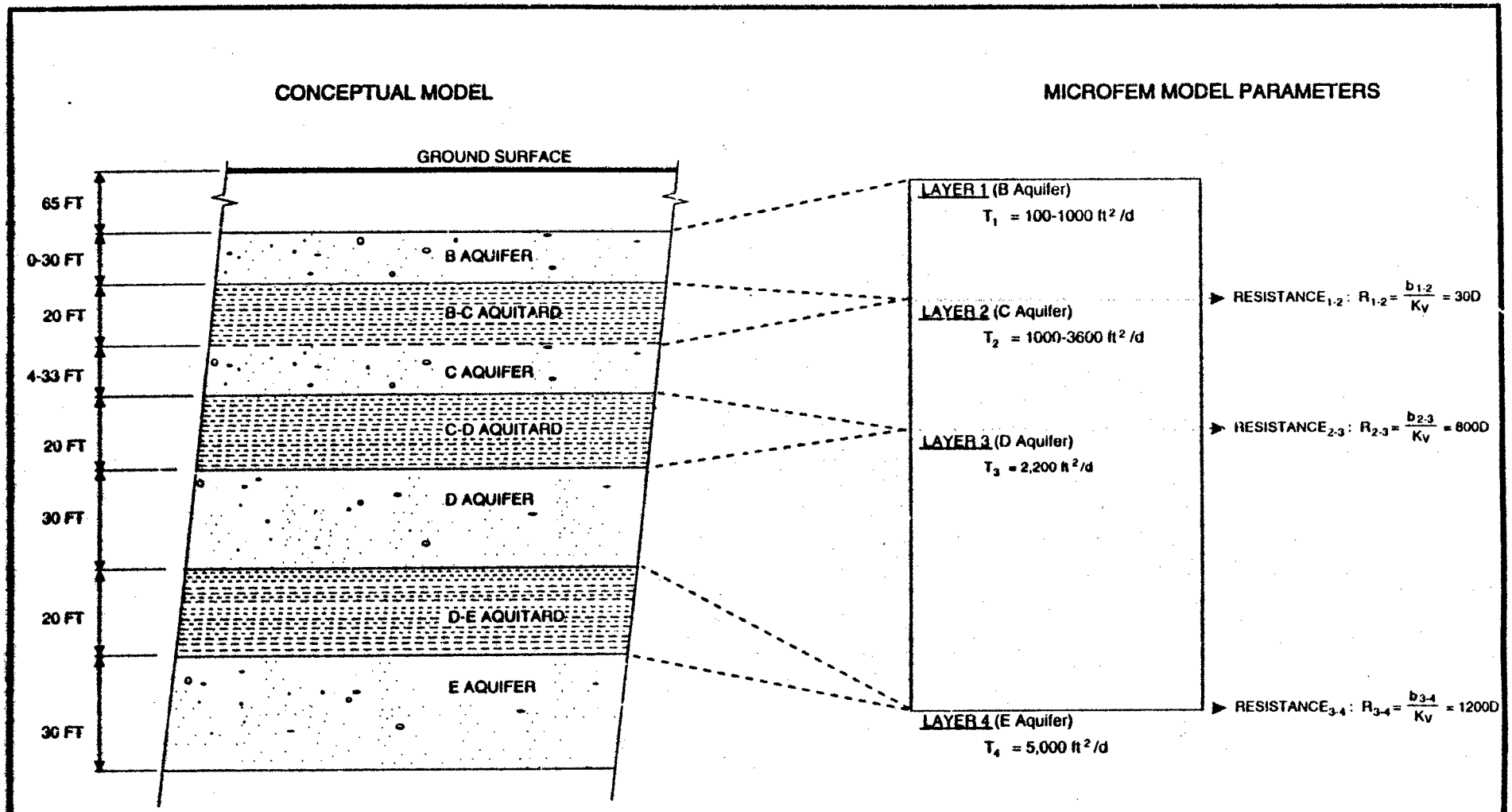

FIGURE J-3
CONCEPTUAL MODEL AND PARAMETERS USED IN GROUNDWATER MODEL

DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_222

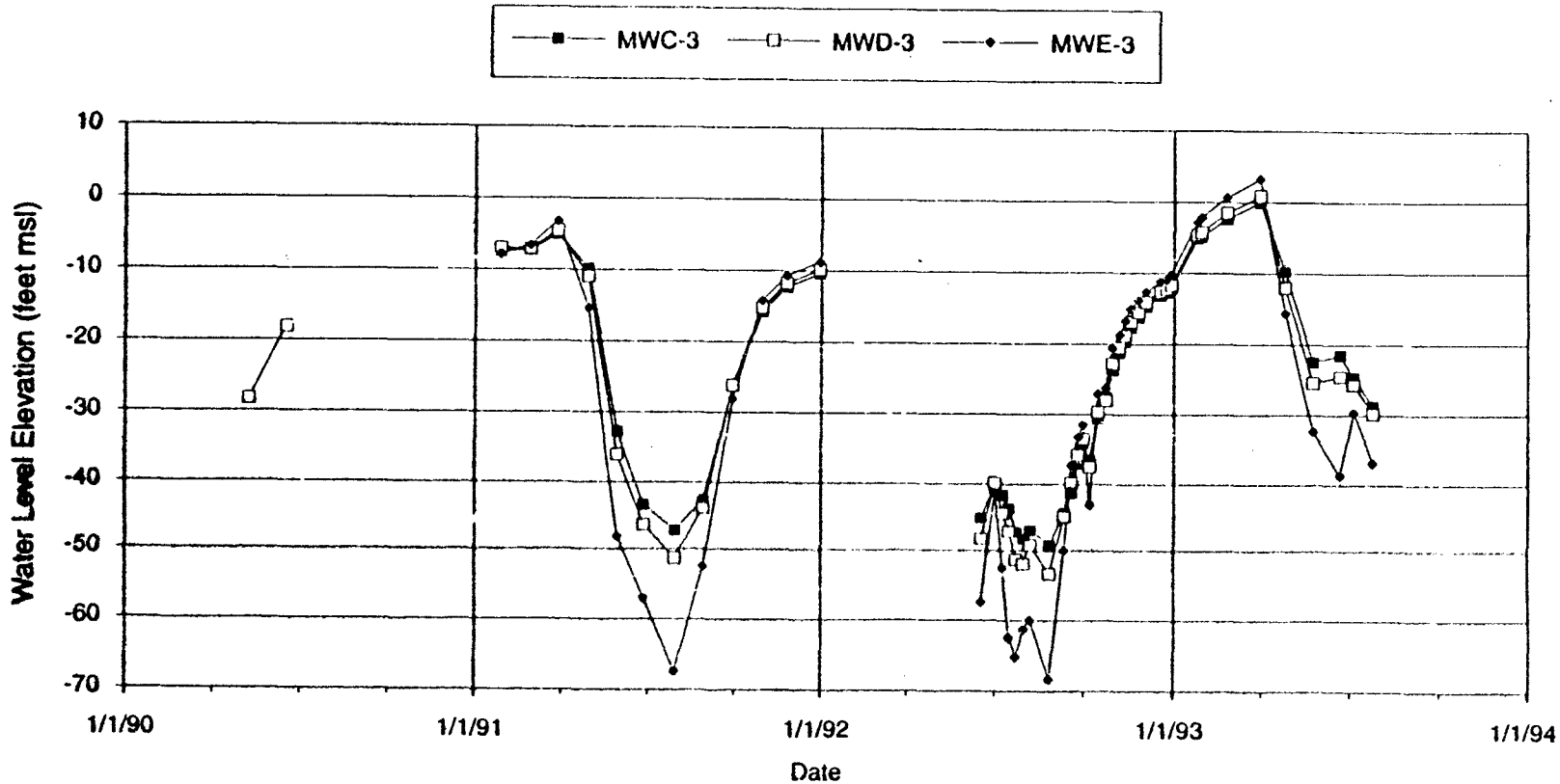

FIGURE J-4
WATER LEVEL HYDROGRAPHS
WELL CLUSTER MW3
DAVIS GLOBAL COMMUNICATIONS SITE

another at most locations at the site. The B and C aquifers appear to be interconnected aquifers or permeable zones. Figure J-4 also shows that water levels in the B and C aquifers fluctuate up to 40 feet in 6 months. The hydraulic head in the D and E aquifers fluctuates up to 65 feet within 6 months. Also, it appears that the vertical gradients are usually downward in the summertime due to regional agricultural pumping and upward in the wintertime when the aquifer is recovering. A lack of long-term and consistent water level data exists for the site.

Because of the effects of agricultural pumping near the site, groundwater flow directions and flow rates within aquifers beneath the site are variable. The wintertime condition is characterized by northwesterly groundwater flow in the B and C aquifers, high groundwater levels (30 to 40 feet bls), and a relatively low horizontal gradient of 0.001 foot/foot. Summertime conditions are characterized by southerly groundwater flow, lower groundwater levels (60 to 70 feet bls), and a significantly steeper horizontal gradient of 0.01 foot/foot. Groundwater contour maps are presented in Appendix E.

Contaminated groundwater has been detected in samples from B, C, D, and E aquifer monitoring wells. A summary of analytical results for groundwater samples collected in February 1993 (Radian, 1993) is provided in Table J-1. These results are the basis for the target areas defined in the next section. The main contaminants are VOCs, of which TCE has been found at the highest concentrations. Contamination has also been detected in the site production well which is perforated in the C and D aquifers.

Target Areas

Figures J-5, J-5a, J-5b, J-6a, and J-6b show the target areas for groundwater extraction. They are the areas for which groundwater should flow to the extraction wells during pumping. The four target areas have been delineated on the basis of available groundwater flow and groundwater quality data. The target areas for each aquifer are presented in Table J-2. These target areas apply to the aquifers previously termed by the International Technology Corporation (ITC) in 1992 as the B, C, D, and E aquifers at the site. In this memo, the terms "B", "C", "D", and "E aquifers" have been retained for convenience in discussion. However, these zones may not be laterally continuous across the site and, as such, may not be correlatable stratigraphic units. Rather, they loosely define depth zones beneath the site. The target areas approximately encompass the area in which contamination has been detected through the July 1993 sampling.

Water quality results from the July 1993 sampling indicate that contamination has spread in the C, D, and E aquifers. However, the results from additional groundwater modeling indicate that extraction rates presented within this appendix are adequate to capture the expanded target areas within the C, D, or E aquifers.

Table J-1
EPA 8010/8020 Analytes Detected in February 1993

Well	Analyte Detected (µg/l)						
	1,1-DCE	cis-1,2-DCE	Chloroform	PCE	TCE	Vinyl Chloride	1,1-DCA
MW-1	2.8	24	ND	8.1	27	7.5	ND
MW-2	24	30	ND	34	180	ND	ND
MW-3	49	410	ND	170	350	82	ND
MW-4	ND	.41	.49	.12	4.9	ND	ND
MW-5	53	ND	ND	350	37	ND	ND
MW-6	ND	ND	ND	1.6	6.7	ND	ND
MW-7	7	24	ND	6.7	70	ND	ND
MW-8	2.7	2.6	ND	.33	16	ND	.73
MWB-1	ND	ND	ND	1.7	5.8	ND	ND
MWB-4	ND	ND	ND	.3	ND	ND	ND
MWB-11	ND	ND	ND	ND	ND	ND	ND
MWB-13	ND	ND	ND	ND	ND	ND	ND
MWB-14	ND	.53	ND	ND	.95	ND	ND
MWC-1	ND	ND	ND	ND	ND	ND	ND
MWC-3	ND	.72	1.4	38	21	ND	ND
MWC-4	ND	ND	ND	ND	ND	ND	ND
MWC-12	ND	ND	ND	1.1	2.7	ND	ND
MWC-13	ND	ND	ND	ND	ND	ND	ND
MWC-14	ND	.5	ND	ND	.32	ND	ND
MWD-1	ND	ND	ND	ND	ND	ND	ND
MWD-2	ND	ND	ND	.33	.78	ND	ND
MWD-3	ND	1.3	ND	26	29	ND	ND
MWD-4	ND	ND	ND	ND	.28	ND	ND
MWD-10	ND	.52	ND	ND	6	ND	ND
MWD-11	ND	ND	ND	ND	.47	ND	ND
MWD-12	ND	ND	ND	5.9	13	ND	ND
MWD-13	ND	ND	ND	ND	1.2	ND	ND
MWD-14	ND	.68	ND	.79	15	ND	ND
MWE-3	ND	ND	ND	ND	.31	ND	ND

Source: Radian 1993.
ND: Not Detected. Data qualifiers are not shown.

Table J-2 Aquifer Target Areas				
	B Aquifer	C Aquifer	D Aquifer	E Aquifer
Target Area (ft^2)	453,000	649,350	969,000	950,000

Generally, the groundwater contamination concentrations within the B aquifer are the highest at the site. Groundwater contamination concentrations generally decrease with depth at the site.

Groundwater movement is slightly upward from the lower-lying E and D aquifers to the C and B aquifers at the site during the wintertime when there is no agricultural pumping. Therefore, a tendency for downward movement of contamination during the winter months does not exist. Groundwater moves downward during summertime conditions when nearby agricultural wells are pumping from deeper aquifers. Hydraulic containment of the groundwater contamination was evaluated for both the winter and summer water level conditions.

Capture Zone Evaluation

Objectives

The objectives of the groundwater extraction system are to:

- Hydraulically capture the contaminated groundwater within the established target areas under summertime and wintertime flow conditions
- Create or maintain upward gradients from the lower aquifers (D and E) to the upper aquifers (B and C) at the target area boundaries throughout the year

Approach

A capture zone analysis was performed to determine the well locations and extraction rates that hydraulically contain or capture groundwater within a target area for a wide range of groundwater conditions. Two time periods were selected to represent typical extreme groundwater flow conditions. The following scenarios were evaluated to determine well locations and extraction rates to capture groundwater in the target areas in the B, C, D, and E, aquifers:

- Wintertime Flow Conditions (March 1993): High water level/flat horizontal gradient/upward vertical gradient
- Wintertime Flow Conditions (March 1993) with reinjection

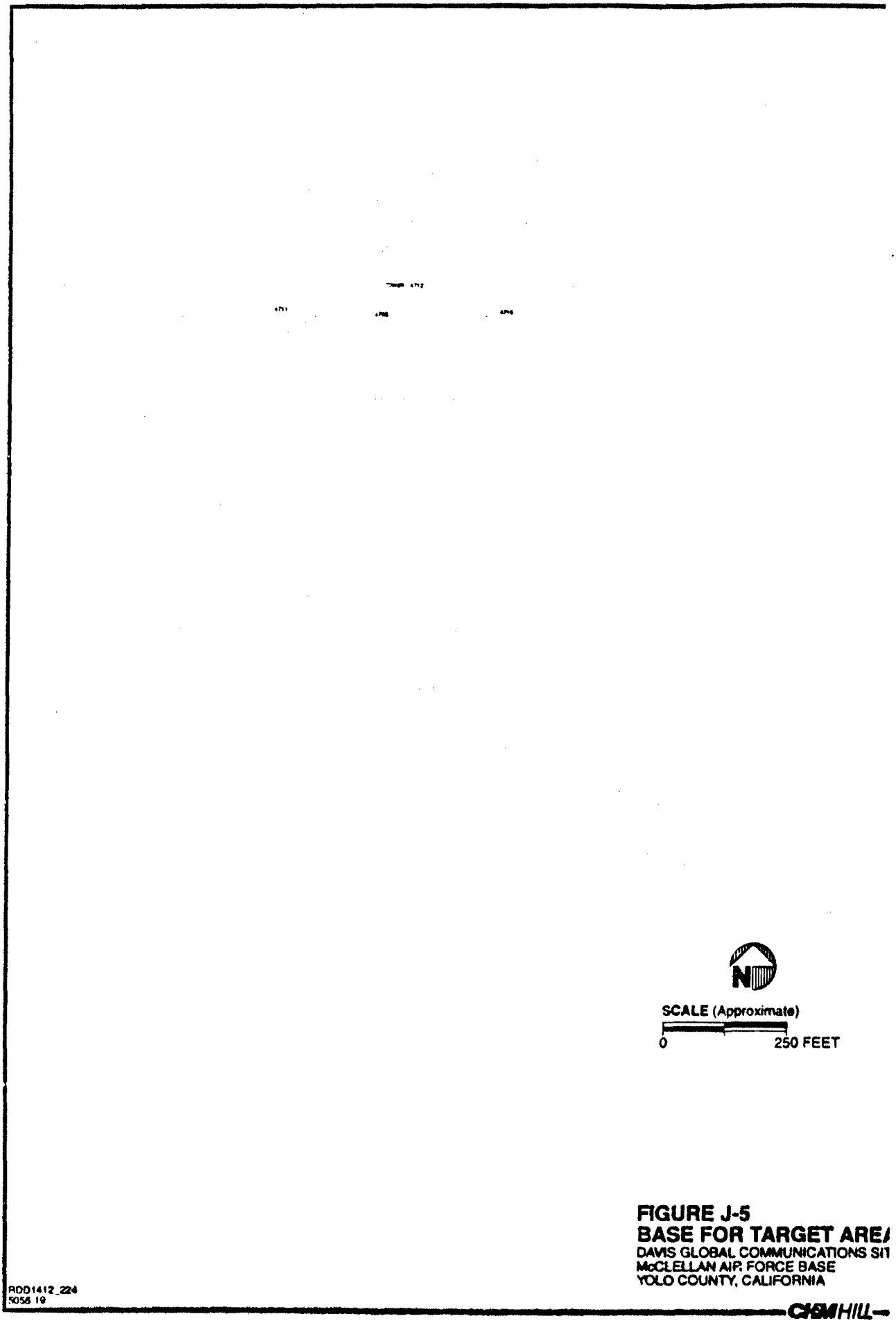

FIGURE J-5
BASE FOR TARGET ARE/
DAVIS GLOBAL COMMUNICATIONS SI1
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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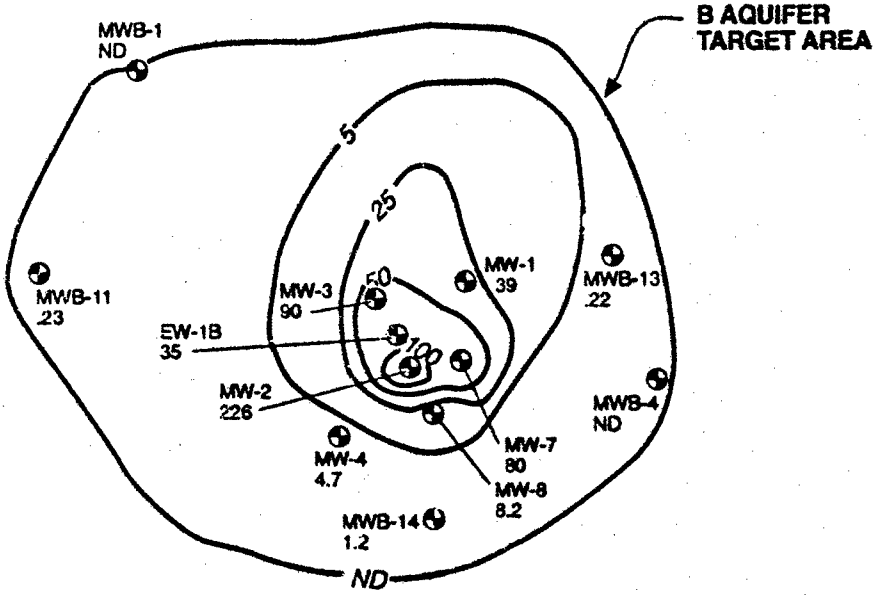

LEGEND

GROUNDWATER MONITORING WELL

5 B AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

FIGURE J-5a
B AQUIFER TARGET AREA
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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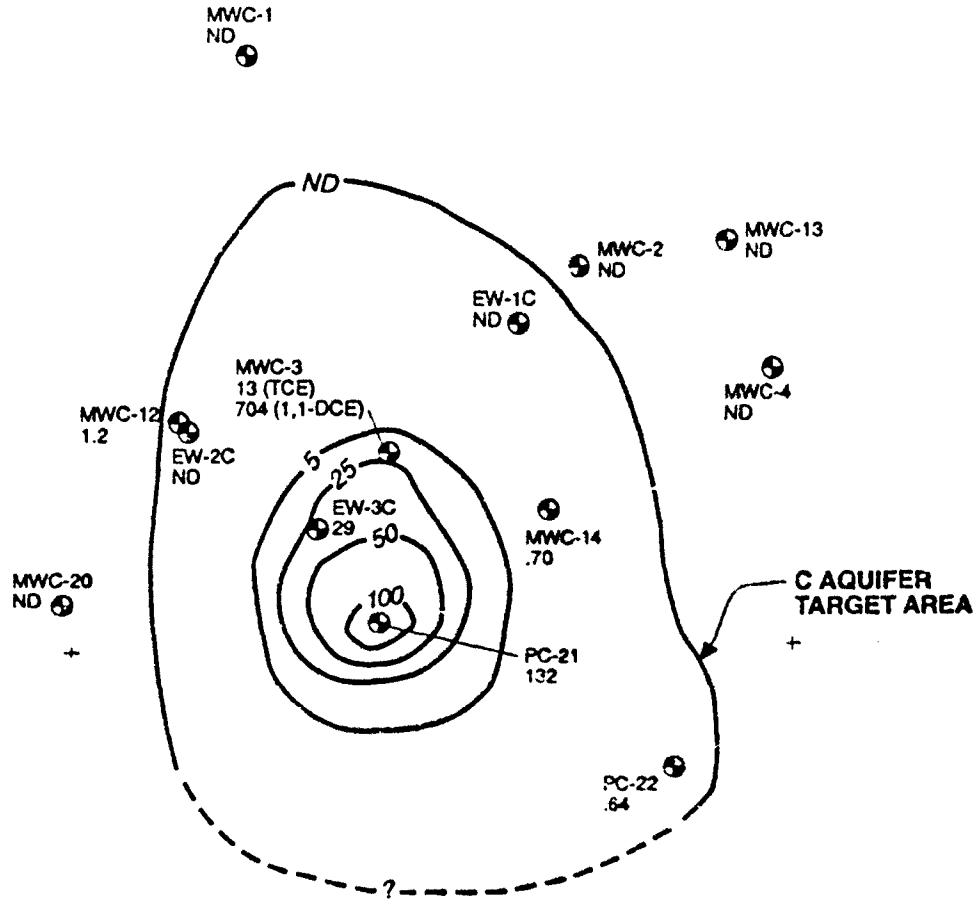
3066.19



LEGEND

GROUNDWATER MONITORING WELL

5 C AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

FIGURE J-5b
C AQUIFER TARGET AREA
DAVIS GLOBAL COMMUNICATIONS SIT
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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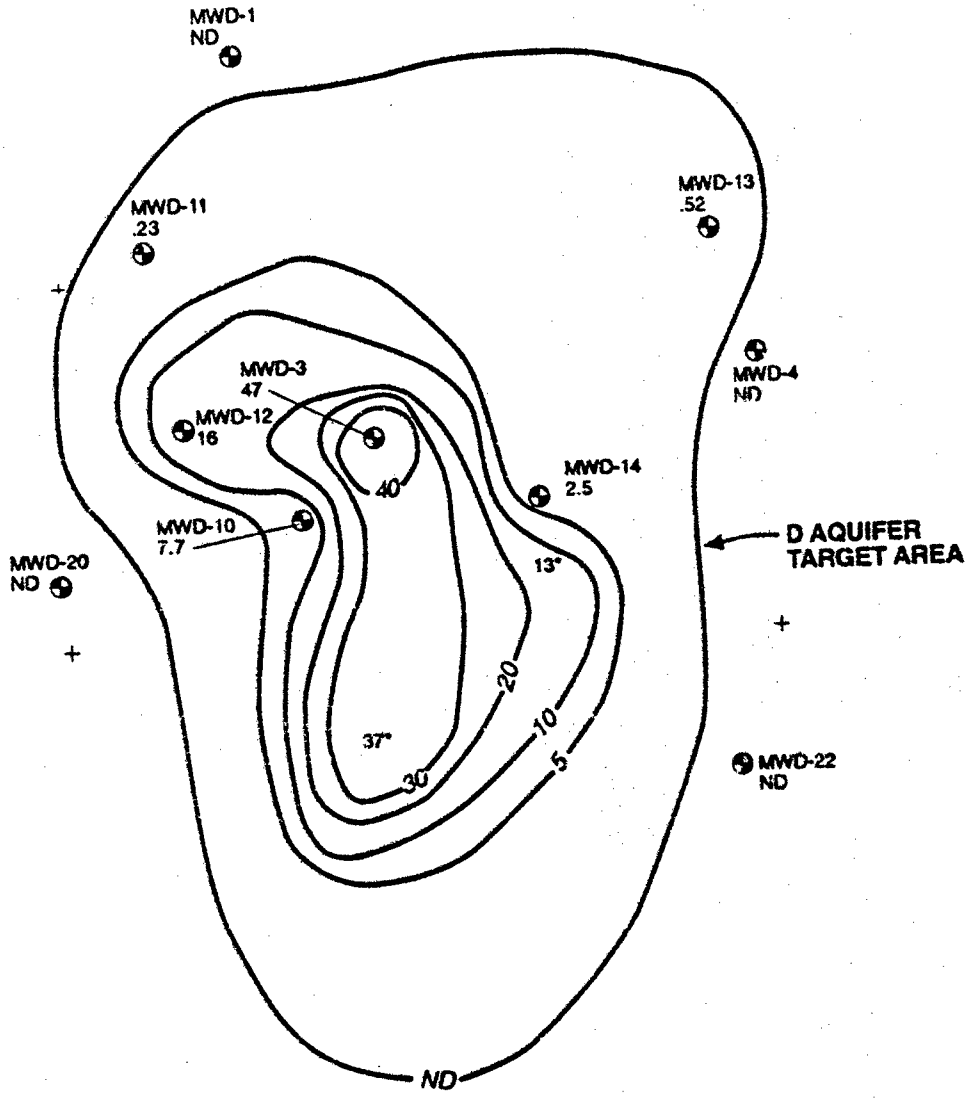

LEGEND

GROUNDWATER MONITORING WELL

30 D AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

• SAMPLES TAKEN DURING DRILLING

FIGURE J-6a
D AQUIFER TARGET ARE
DAVIS GLOBAL COMMUNICATIONS SI
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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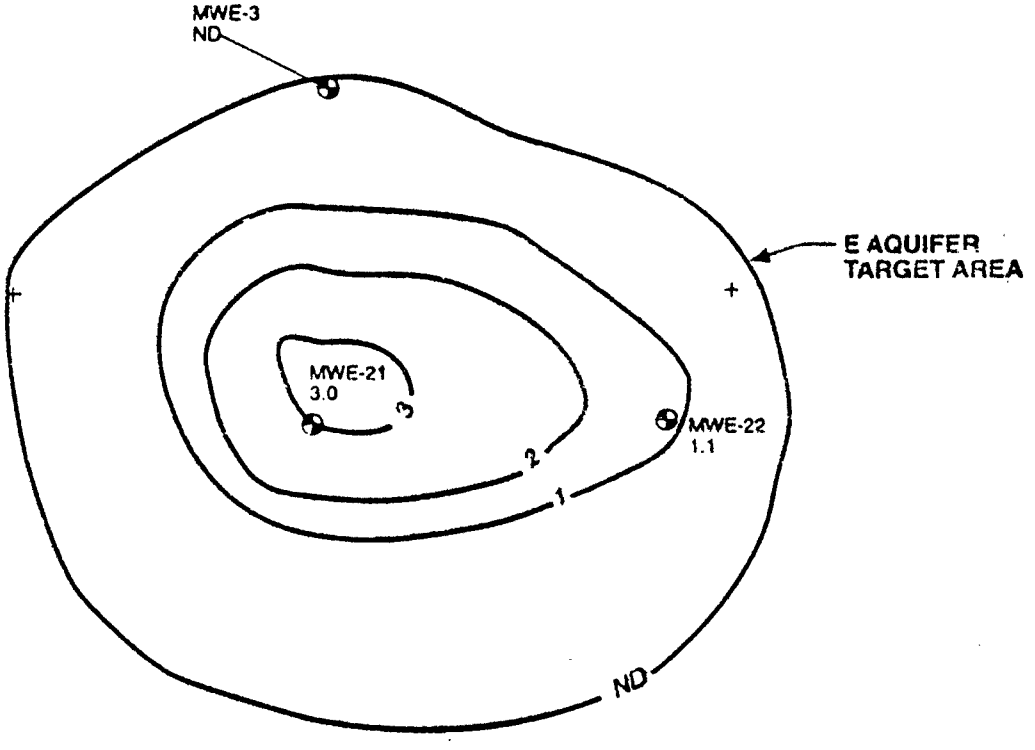

LEGEND

GROUNDWATER MONITORING WELL

3 E AQUIFER TCE CONCENTRATIONS (µg/l), 7/93

FIGURE J-6b
E AQUIFER TARGET ARE
DAVIS GLOBAL COMMUNICATIONS SI
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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- Summertime Flow Conditions (July 1993): Low water level/steeper horizontal gradient/downward vertical gradient

- Summertime Flow Conditions (July 1993) with reinjection

Extraction well locations were selected from modeling calculations. Actual locations were used for Extraction Wells EW-1B, EW-2C, EW-3C, EW-1D, EW-2D, and EW-3D.

The capture zone analysis was performed using the steady-state finite element model MicroFem (Hemker, et al., 1988). The steady-state analysis was used to evaluate capture for winter and summer groundwater flow conditions. If groundwater capture can be obtained for the extreme conditions of winter and summer, then it will be obtained for intermediate conditions. The MicroFem model allows up to four layers and can incorporate heterogeneous transmissivities. A vertical resistance between each layer must be specified. Four layers were used to represent the B, C, D, and E aquifers. Figure J-3 shows how the model parameters represent the conceptual model of the subsurface. The finite element grid dimensions are 10,000 feet by 10,000 feet, with the site nearly centered, as shown in Figure J-7. The grid consists of 2,186 nodes and 4,318 elements. The node spacing ranges from approximately 50 feet within the target areas to 500 feet near the edge of the grid.

Transmissivity estimates for each aquifer are given in Table J-3. The transmissivity of the B aquifer was estimated using the MW-3 aquifer test results and specific capacity information from development pumping of EW-1B. The transmissivity distribution within the B aquifer target area and within 500 feet surrounding the target area was estimated by interpolating measured transmissivity values. Outside of this area, the transmissivity of the B aquifer was specified to be 1,000 ft^2/day. The transmissivity values range from 100 to 1,000 ft^2/day across the site.

Table J-3
Aquifer Transmissivity Values Used in Model

	B Aquifer	C Aquifer	D Aquifer	E Aquifer
Transmissivity (ft^2/day)	100 to 1,000	1,000 to 3,600	2,200	5,000

The C aquifer transmissivity was estimated based on aquifer test results and results from development pumping of the new extraction wells EW-1C, EW-2C, and EW-3C. The transmissivity distribution of the C aquifer within the target area was generated by the same method used for the B aquifer. Outside of the C aquifer target area, the transmissivity was set at 2,250 ft^2/day. The transmissivity values for the C aquifer range from 950 to 3,600 ft^2/day across the site.

The transmissivity of the D aquifer was set equal to 2,200 ft^2/day everywhere in the model grid based on aquifer test results (CH2M HILL, March 1993). The transmissivity of the E aquifer was set equal to 5,000 ft^2/day.

Different boundary conditions were used for the low water level and high water level scenarios. The contour maps of water levels in the B, C, and D aquifers in March 1993 (wintertime) and July 1993 (summertime) are attached. Water levels in the E aquifer are presented for the July period because of additional wells installed during April and May 1993. The boundary conditions were selected to generate similar flow conditions. Figure J-8 shows the boundary conditions applied for the wintertime and summertime scenarios.

Uncertainties

The main uncertainties in the numerical model are:

- Heterogeneities
- Vertical resistance

Limited transmissivity data are available to specify how transmissivity varies spatially at the site. Heterogeneities in transmissivity were incorporated using lithologic information as discussed in the previous section. The vertical resistance between each aquifer was specified to be constant throughout the grid. The simulation results are sensitive to the value input for vertical resistance.

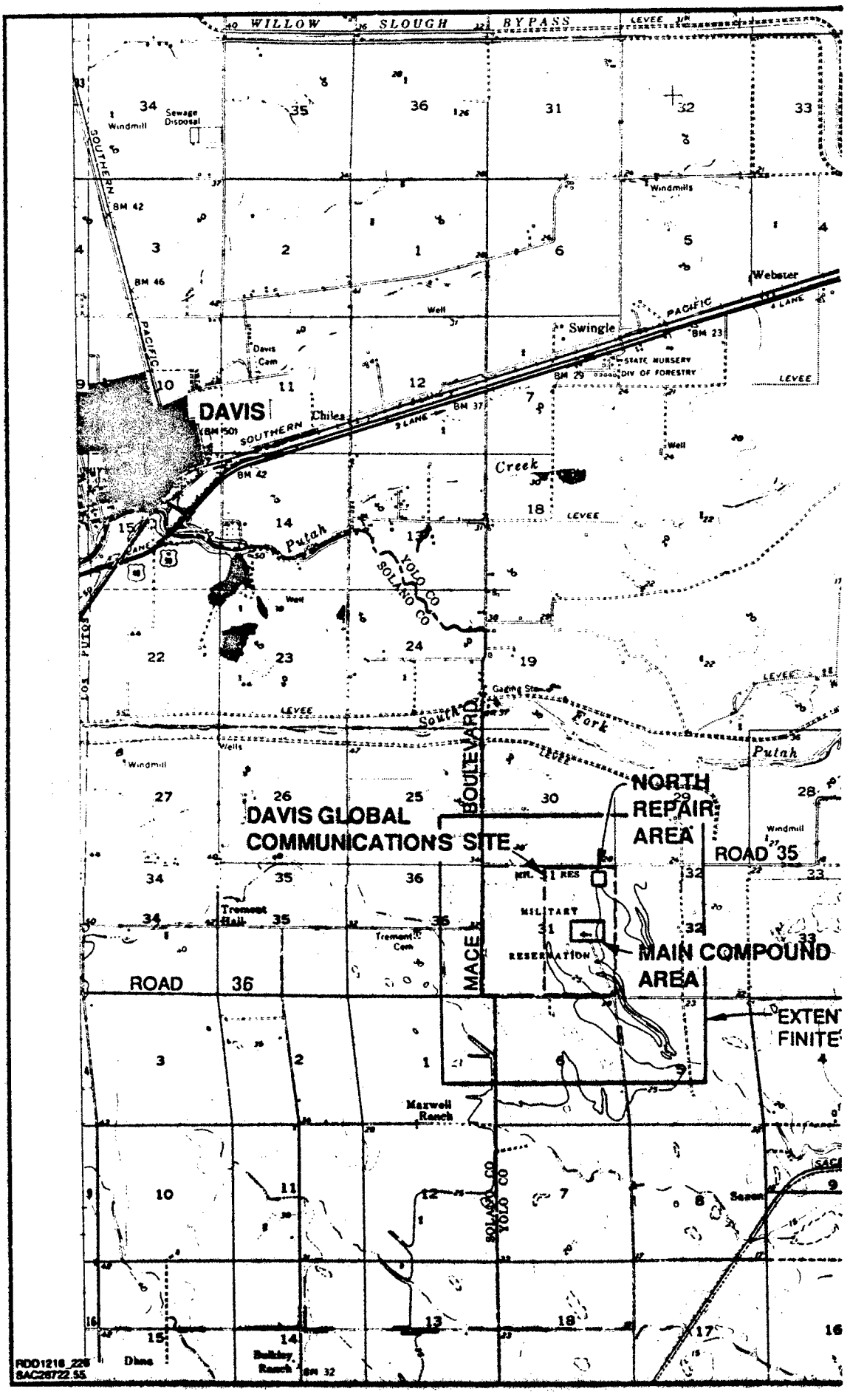
Results

Wintertime Flow Conditions

Figures J-9 through J-12 present the simulation results for the wintertime flow conditions. For wintertime flow conditions, extraction well pumping was simulated at one-third the rate as for summertime conditions to evaluate if capture was attained for each target area. The simulated pumping rates for each extraction well are presented in Table J-4. Pumping rates for the extraction wells were estimated based on development pumping results for the B and C aquifer wells. Pumping rates for the D and E aquifer wells were estimated based on transmissivity values for each respective aquifer.

Table J-4
Extraction Rates Simulated in Model to Obtain Capture
Wintertime Flow Conditions

Well Name	Extraction Rate (gpm)
EW-1B	20 to 25
EW-2C	20 to 25
EW-3C	15 to 20
EW-4C	30 to 40
EW-1D	25 to 35
EW-2D	20 to 30
EW-3D	25 to 35
EW-1E	30 to 40
EW-2E	20 to 25
Total	205 to 275


WILLOW SLOUGH BYPASS
LEVEE
Sewage Disposal
Windmill
SOUTHERN PACIFIC
BM 42
BM 46
Windmills
Webster
Swingle
PACIFIC
4 LANE
BM 23
STATE NURSERY
DIV OF FORESTRY
BM 29
Davis Cem
DAVIS
(BM 50)
SOUTHERN
Chiles
BM 37
3 LANE
Creek
Putah
YOLO CO
SOLANO CO
LOS PUTOS
South Fork
Putah
Gaging Sta
Wells
Windmill
BOULEVARD
MACE
NORTH REPAIR AREA
DAVIS GLOBAL COMMUNICATIONS SITE
ROAD 35
MIL. RES
MILITARY RESERVATION
MAIN COMPOUND AREA
Tremont Hall
Tremont Cem
ROAD 36
EXTEN
FINITE
Maxwell Ranch
SOLANO CO
YOLO CO
Saxon
Dana
Bulkley Ranch
BM 32
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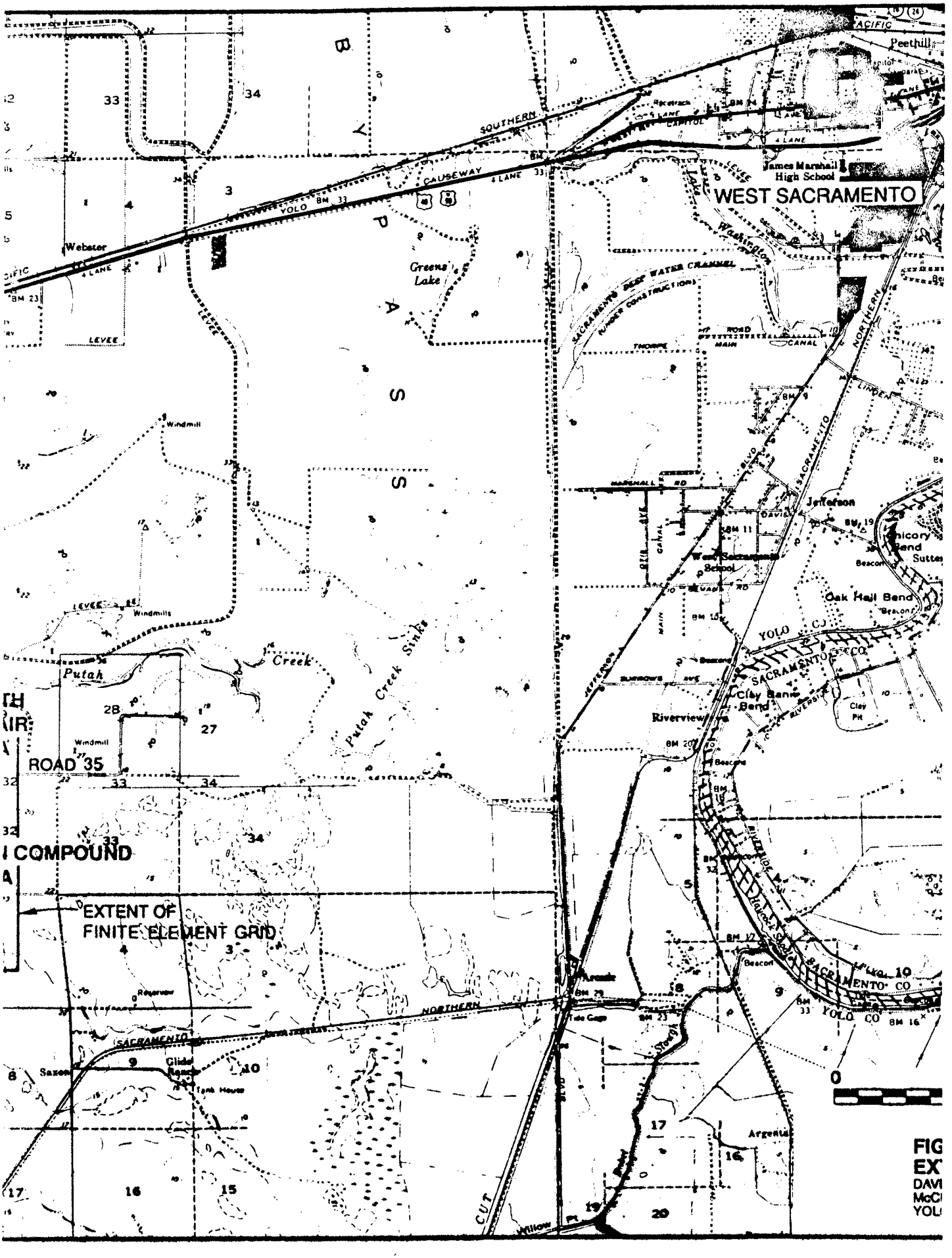

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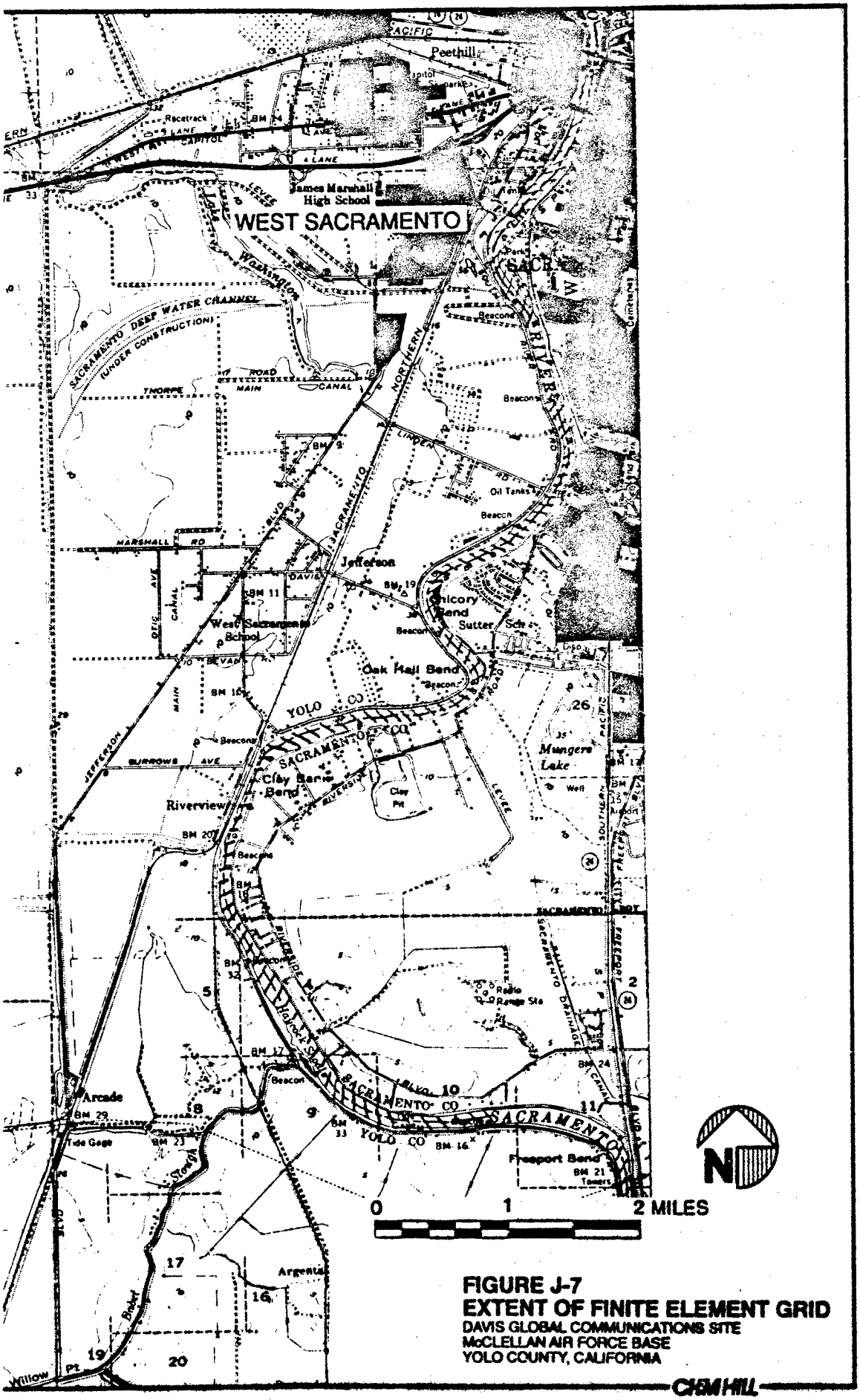
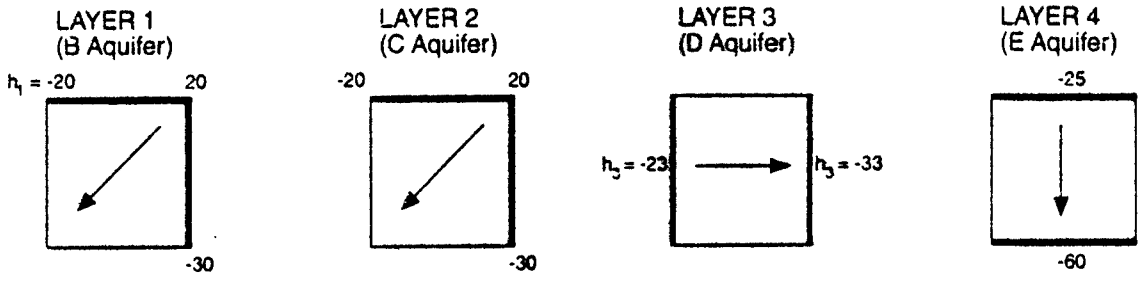


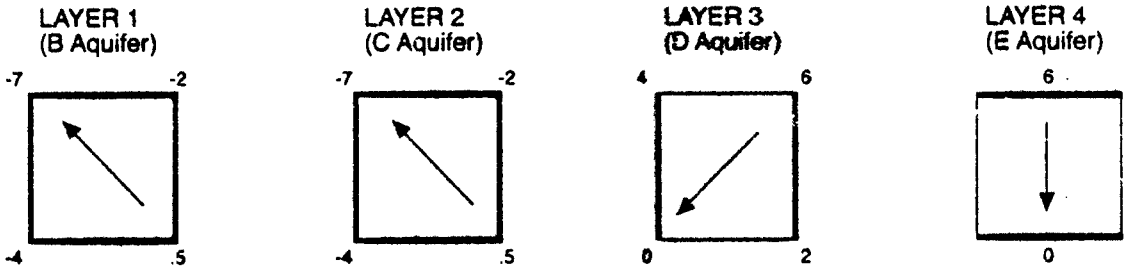
FIGURE J-7
EXTENT OF FINITE ELEMENT GRID
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2M HILL

SUMMERTIME



WINTERTIME



LEGEND

- Represents 10,000 ft x 10,000 ft grid
- Fixed head condition
- Variable head condition
- Gradient direction

FIGURE J-8
MODEL BOUNDARY CONDIT
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

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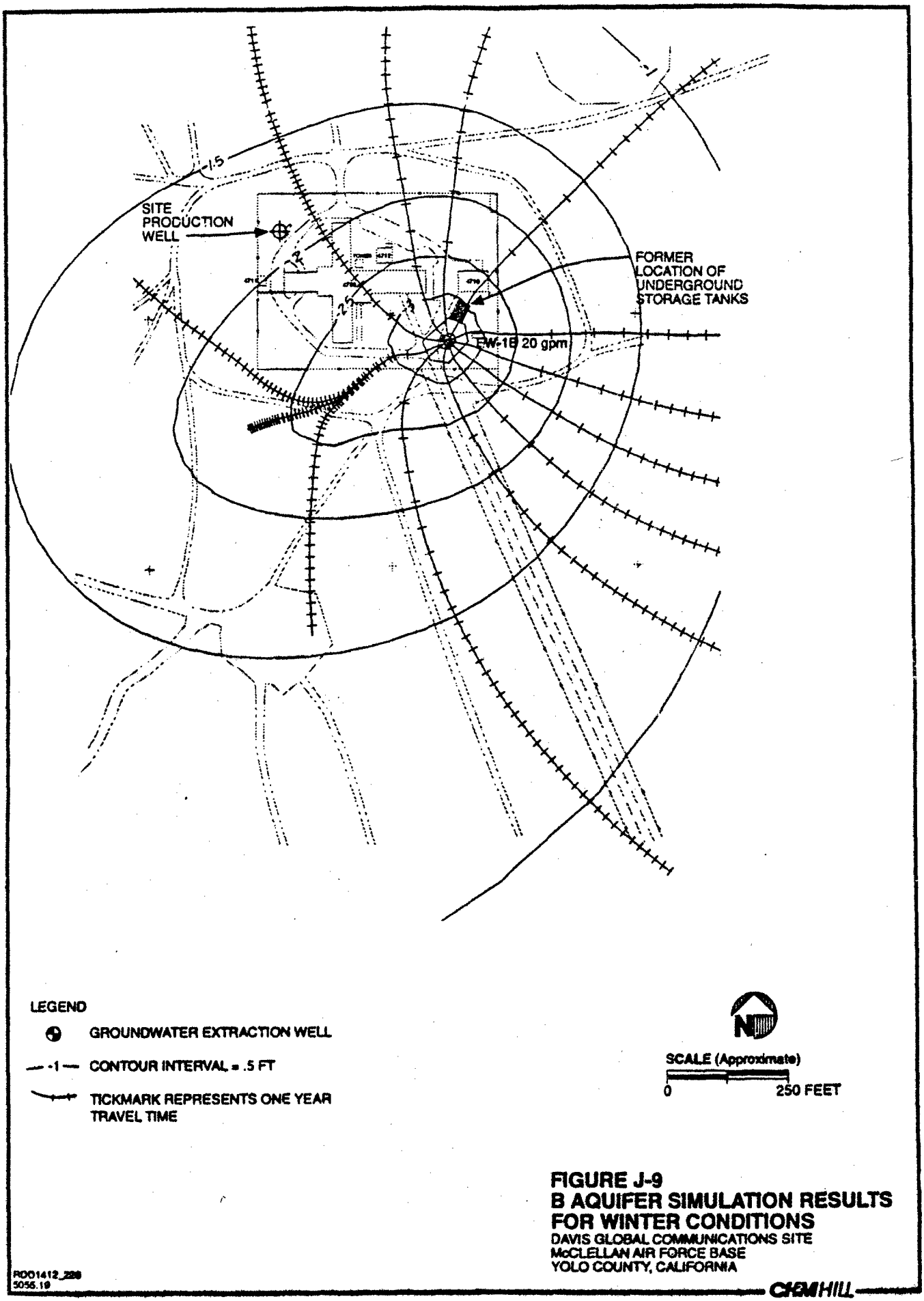

FIGURE J-9
B AQUIFER SIMULATION RESULTS FOR WINTER CONDITIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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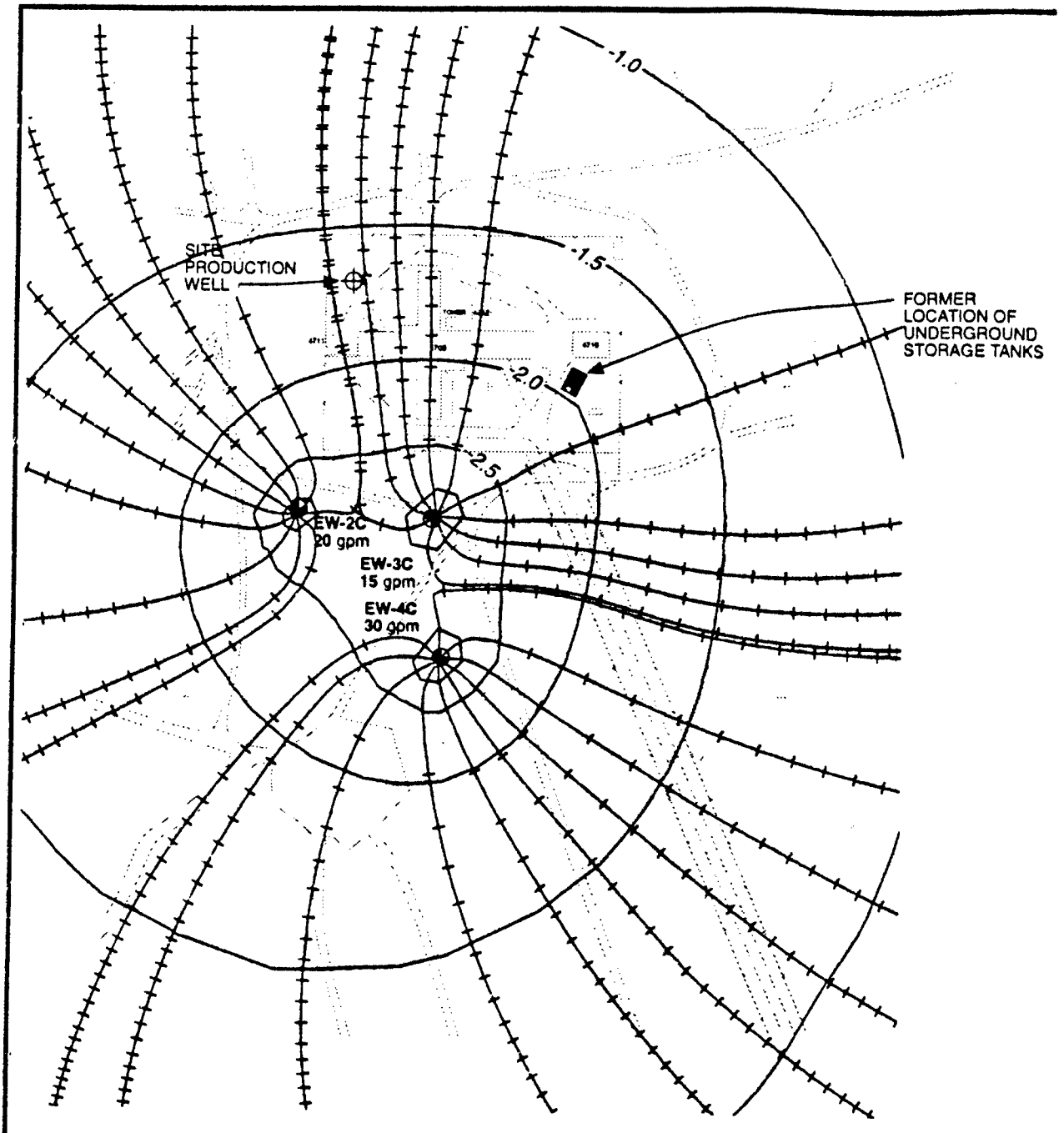
5056.19

CH2MHILL



LEGEND

- GROUNDWATER EXTRACTION WELL
- -1- CONTOUR INTERVAL = .5 FT
- TICKMARK REPRESENTS ONE-HALF YEAR TRAVEL TIME

N

SCALE (Approximate)

0 250 FEET

FIGURE J-10
C AQUIFER SIMULATION RESUL
FOR WINTER CONDITIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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CH2MHILL

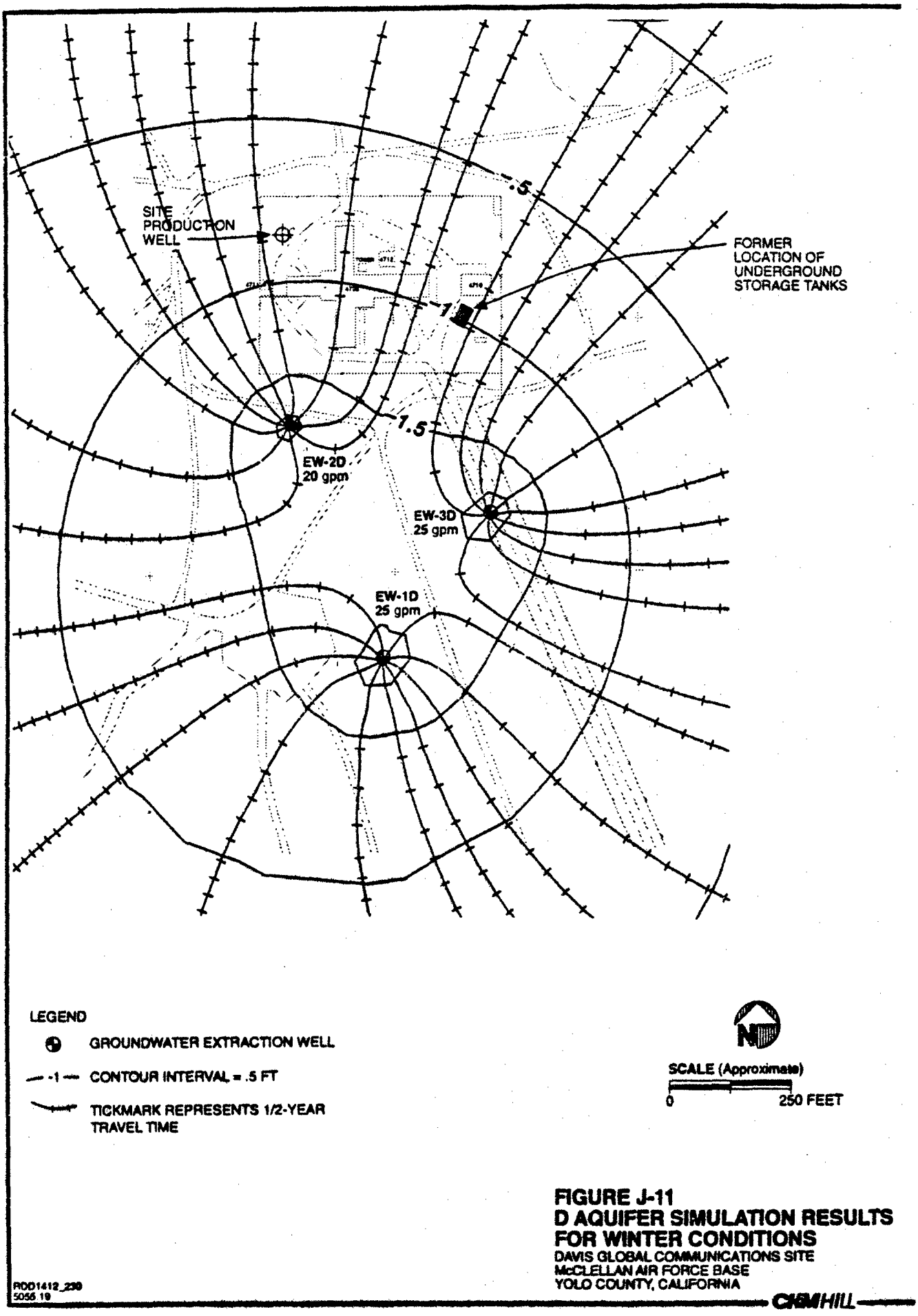

FIGURE J-11
D AQUIFER SIMULATION RESULTS FOR WINTER CONDITIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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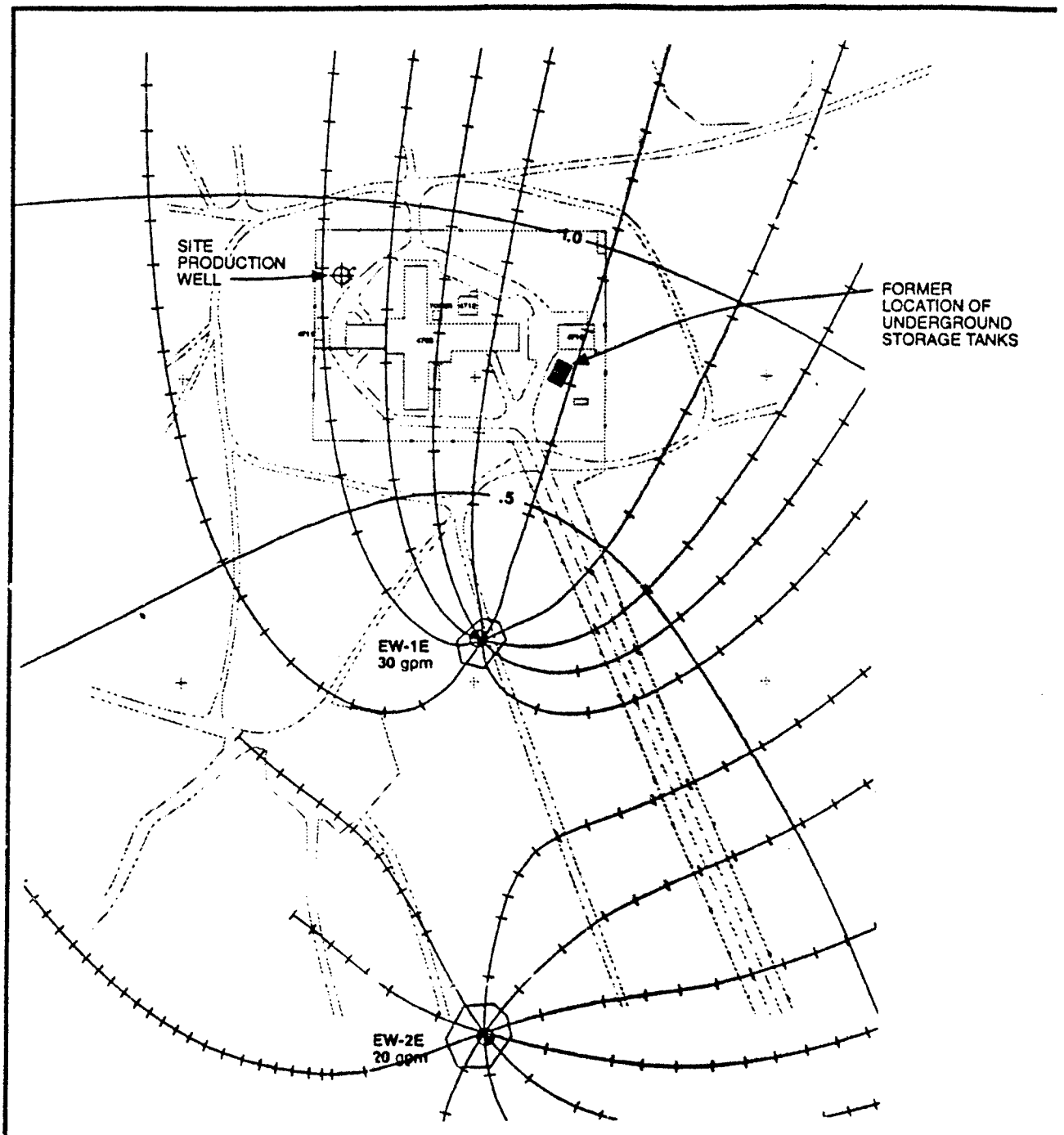

LEGEND

- GROUNDWATER EXTRACTION WELL
- -1- CONTOUR INTERVAL = .5 FT
- TICKMARK REPRESENTS 1/2-YEAR TRAVEL TIME

SCALE (Approximate)

0 250 FEET

FIGURE J-12
E AQUIFER SIMULATION RESULTS FOR WINTER CONDITIONS
DMVS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Contours of groundwater elevation and flowlines to each extraction well for the B, C, D, and E aquifers are shown in Figures J-9 through J-12. Horizontal capture of the target areas is attained with the pumping shown in each figure. Horizontal capture is attained if all of the groundwater within the target area flows to an extraction well or series of extraction wells.

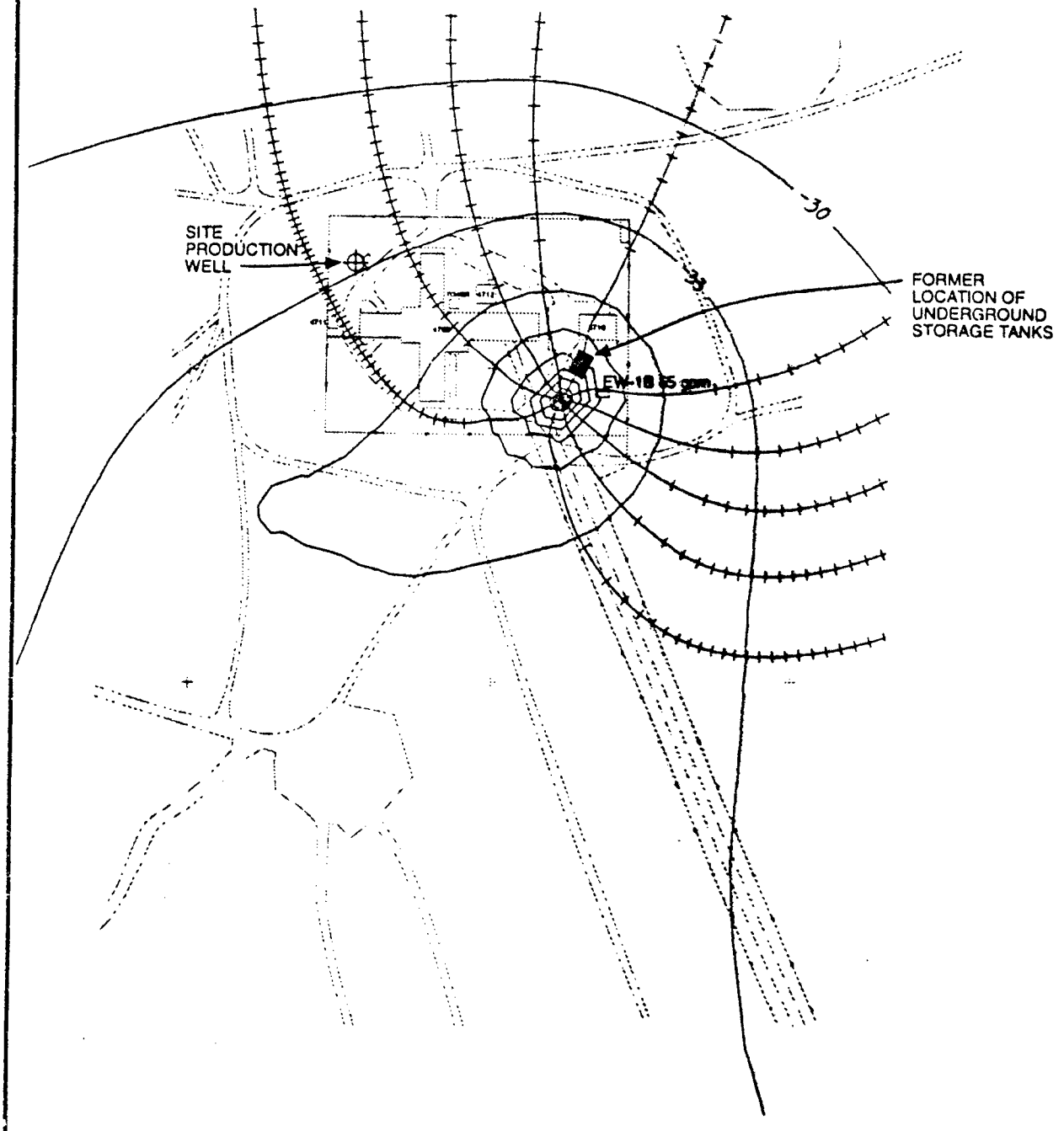
Vertical capture was also evaluated. The goal during groundwater pumping is to have constant upward gradients at the site within the target areas. Upward gradients are a natural condition during the period from about October through April at the site. The most critical period for maintaining upward gradients at the site is during the summertime when natural vertical gradients are downward. Vertical capture was evaluated by comparing the groundwater elevations of each respective aquifer at the target area boundaries. In all cases with the given pumping conditions, groundwater levels were lowest in the B and C aquifers, suggesting that vertical groundwater movement at the boundaries will have a tendency to flow upward. Upward groundwater flow will prevent downward movement of contamination at the site.

Wintertime Flow Conditions with Reinjection as End Use

Reinjection of the extracted groundwater beneath the site is being considered as an end use alternative for the treated water. Reinjection of the total amount of extracted groundwater was simulated at a location approximately 2,000 feet south of EW-1B near the entrance road to the compound. During the reinjection simulation, water was only injected into the E aquifer. Three injection wells were simulated in the vicinity of the entrance road. Total injection rates of 200 to 275 gpm were simulated. Up to 5 feet of groundwater level rise occurred near the reinjection wells. However, capture of groundwater within the target areas was not affected by the mounding of groundwater near the reinjection wells because of the distance between the target areas and the reinjection location. Because limited site-specific hydraulic information is available at the reinjection location, considerable uncertainty exists regarding the actual rise of water levels.

Summertime Flow Conditions

Figures J-13 through J-16 show that groundwater capture is obtained for summertime conditions in each respective target area by pumping each extraction well with the volume given in Table J-5. Vertical capture is obtained at the target area boundaries as well.



LEGEND

- GROUNDWATER EXTRACTION WELL
- -1- CONTOUR INTERVAL = 3 FT
- TICKMARK REPRESENTS 1-YEAR TRAVEL TIME

N

SCALE (Approximate)

0 250 FEET

FIGURE J-13
B AQUIFER SIMULATION RESULTS FOR SUMMER CONDITIONS
DIMS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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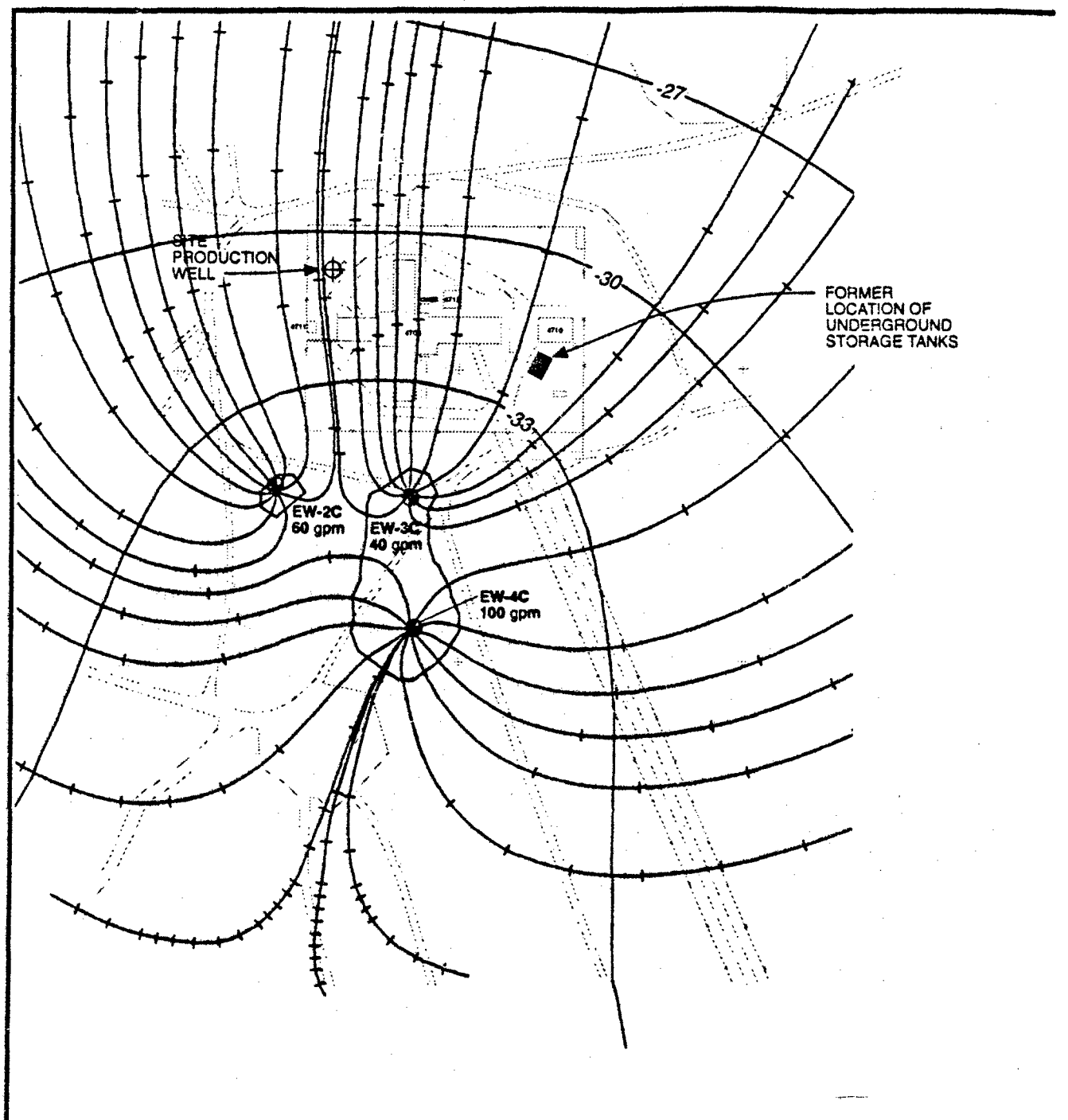

FIGURE J-14
C AQUIFER SIMULATION RESULTS FOR SUMMER CONDITIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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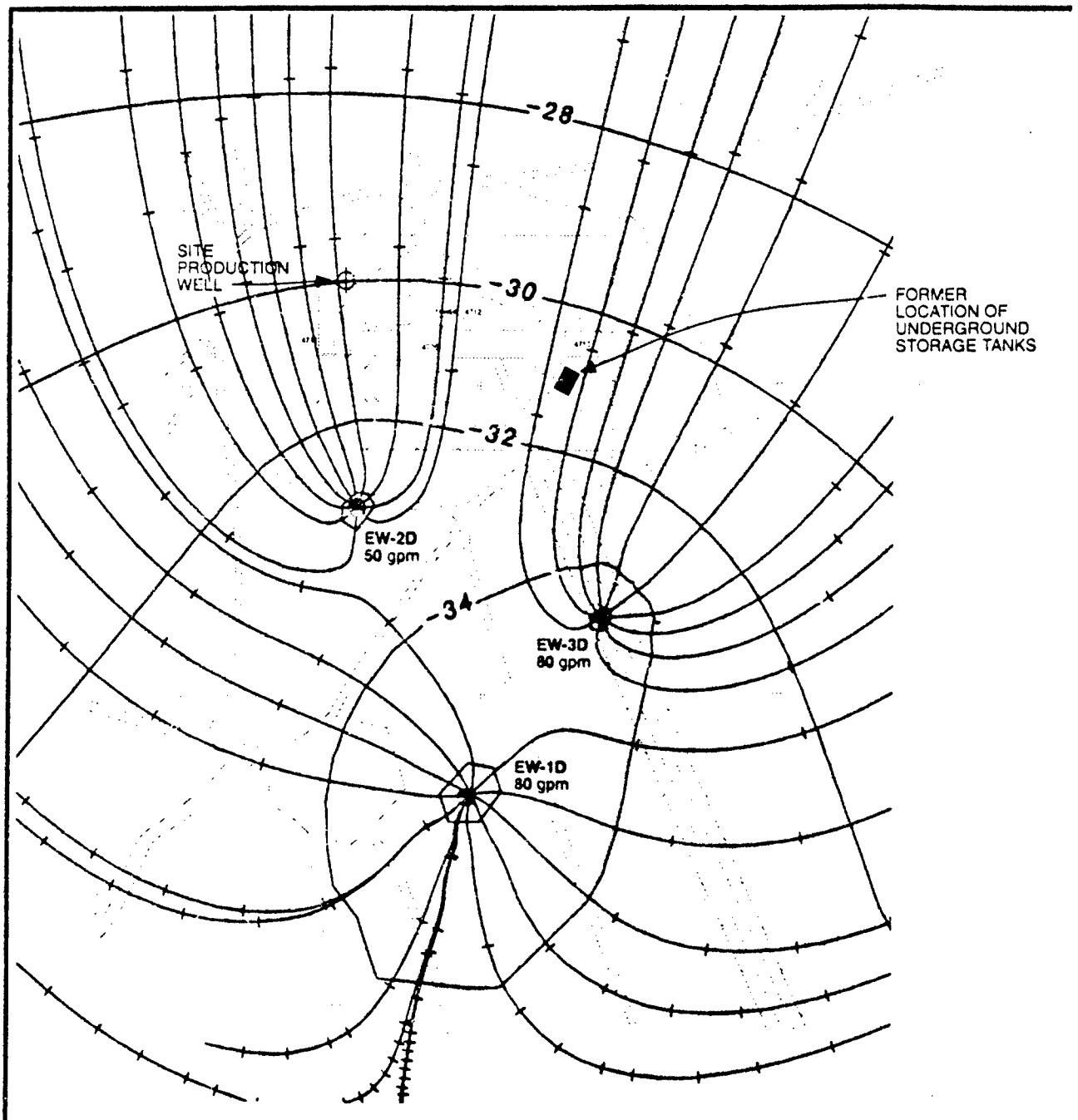

LEGEND

- GROUNDWATER EXTRACTION WELL
- -30- CONTOUR INTERVAL = 2 FT
- TICKMARK REPRESENTS 1/2-YEAR TRAVEL TIME

N

SCALE (Approximate)

0 250 FEET

FIGURE J-15
D AQUIFER SIMULATION RESULT FOR SUMMER CONDITIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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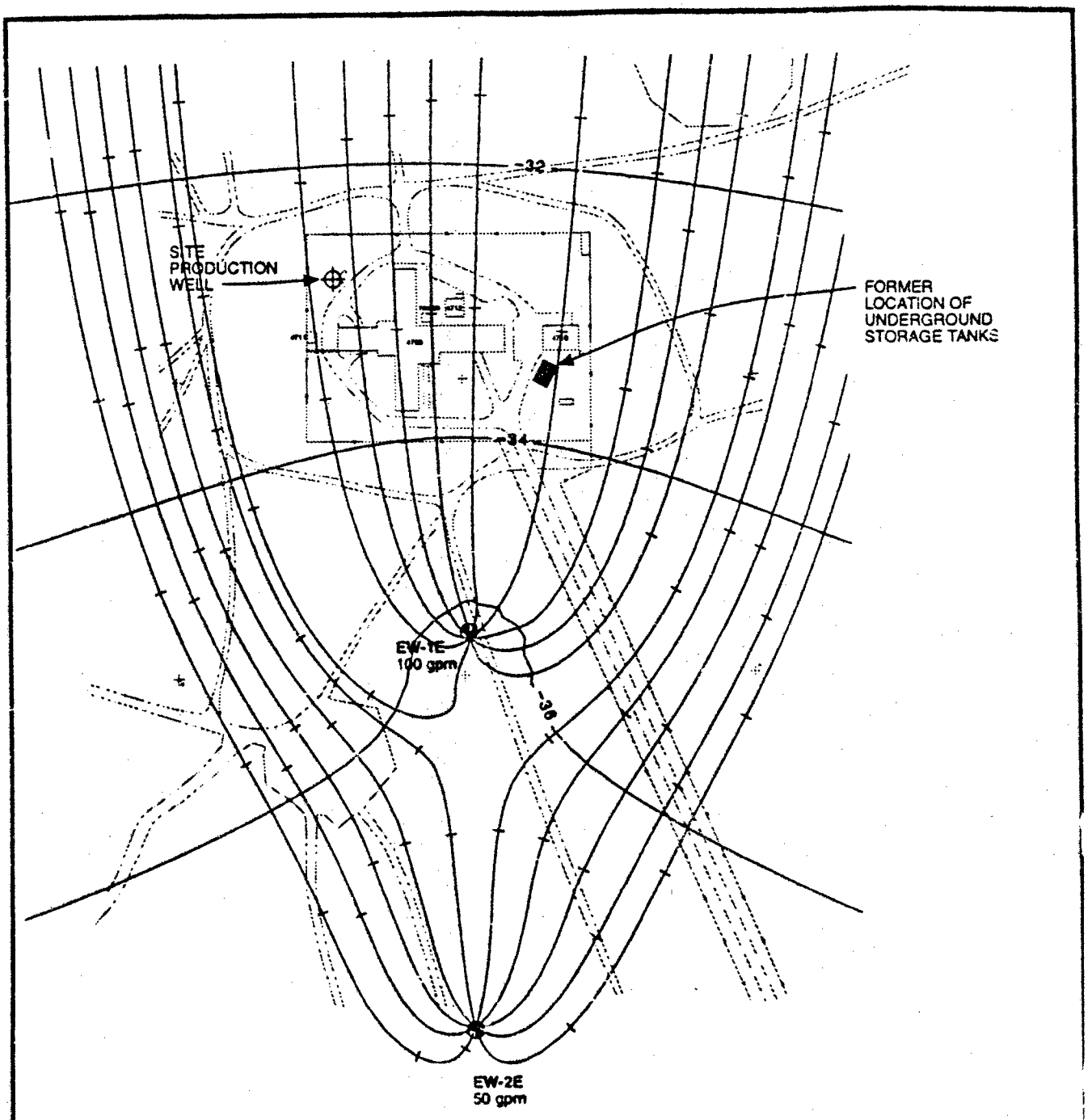

LEGEND

- GROUNDWATER EXTRACTION WELL
- -1- CONTOUR INTERVAL = 2 FT
- TICKMARK REPRESENTS 1/2-YEAR TRAVEL TIME

N

SCALE (Approximate)

0 250 FEET

FIGURE J-16
E AQUIFER SIMULATION RESULTS FOR SUMMER CONDITIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Table J-5 Extraction Rates Simulated in Model to Obtain Capture Summertime Flow Conditions	
Well Name	**Extraction Rate (gpm)**
EW-1B	65 to 80
EW-2C	60 to 100
EW-3C	40 to 50
EW-4C	100 to 150
EW-1D	80 to 100
EW-2D	50 to 60
EW-3D	80 to 100
EW-1E	100 to 120
EW-2E	50 to 60
Total	625 to 820

Simulations were performed to investigate the sensitivity of the resulting capture zone to the total amount extracted from each aquifer. The values presented in Table J-5 represent a range of extraction rates which are likely to achieve capture. The simulations show that capture is obtained with the lower range of flow rates. However, uncertainties in field conditions may warrant increased extraction from any or all wells.

Summertime Flow Conditions with Reinjection as End Use

The reinjection analysis used for the wintertime was repeated for the summertime condition. Three injection wells were simulated in the vicinity of the entrance road. Injection rates of 200 to 210 gpm were simulated. Up to 12 feet of groundwater level rise occurred near the reinjection wells. However, capture of groundwater within the target areas was not affected by the mounding of groundwater near the reinjection wells because of the distance between the target areas and the reinjection location. Because limited site-specific hydraulic information is available at the reinjection location, considerable uncertainty exists regarding the actual rise of water levels.

Extraction Options

Groundwater modeling results and available transmissivity data indicate that contaminated groundwater in the B, C, D, and E aquifers within the target areas can be captured during summertime flow conditions by extracting a total of 625 to 820 gpm. The wintertime pumping only requires 205 to 275 gpm. The estimated mass of contamination per aquifer is shown in Table J-6. Over 80 percent of the mass of contamination is estimated to reside above the C-D aquitard. By reducing

the summertime groundwater extraction from 625 to 820 gpm to 265 to 380 gpm, the simulation results show that over 85 percent of the contaminant mass can be captured. Likewise, the extraction rates for the wintertime can be reduced from 205 to 275 gpm to 85 to 110 gpm. The feasibility study will investigate the associated differences between extracting groundwater from the B and C aquifers versus the B, C, D, and E aquifers. Table J-7 gives the wintertime and summertime flow rates per aquifer to obtain capture.

Table J-6
Estimated Mass of Contamination with Depth

Aquifer/Aquitard Name (Average depth bls in feet)	Mass of Contamination (kg)	Percent	Cumulative Percent
Vadose Zone (0 to 40)	45	13.9	13.9
A/B Aquitard (40 to 65)	64	19.7	33.6
B Aquifer (65 to 95)	82	25.3	58.9
B/C Aquitard (95 to 115)	51	15.7	74.7
C Aquifer (115 to 145)	34	10.5	85.1
C/D Aquitard (145 to 165)	25	7.7	92.8
D Aquifer (165 to 195)	16	4.9	97.7
D/E Aquitard (195 to 215)	7	2.2	99.9
E Aquifer (215 to 245)	0.1	0	100
Total	324		

Table J-7
Estimated Aquifer Extraction Rates (gpm)

Aquifer	Wintertime	Summertime
B	20 to 25	65 to 80
C	65 to 85	200 to 300
Total B and C	85 to 110	265 to 380
D	70 to 90	210 to 260
E	50 to 75	150 to 180
Total	205 to 275	625 to 820

Additional recommendations for seasonal pumping are presented in the Intermediate Remedial Design Report for the Davis Site (CH2M HILL, May 1993). According to the modeling results, a total of six additional extraction wells will be required: one in the C aquifer, three in the D aquifer, and two in the E aquifer.

The recommended extraction well construction details are shown in Figure J-17. Conveyance pipelines will be required from the wells to the collection area or treatment plant if wellhead treatment is not used. Additional facilities required for the extraction system are pumps in the wells and a telemetry control system from the treatment plant to the extraction wells.

Operational Requirements

The operational activities include controlling and adjusting the extraction rates, monitoring water levels and water quality, evaluating data, and possibly installing additional extraction wells. The operation of the extraction system requires data evaluation and decisions throughout the year and during the life of the project because of the changing water levels, groundwater flow directions, and management objectives. A description of the system control, monitoring, and data evaluation activities follows.

System Control

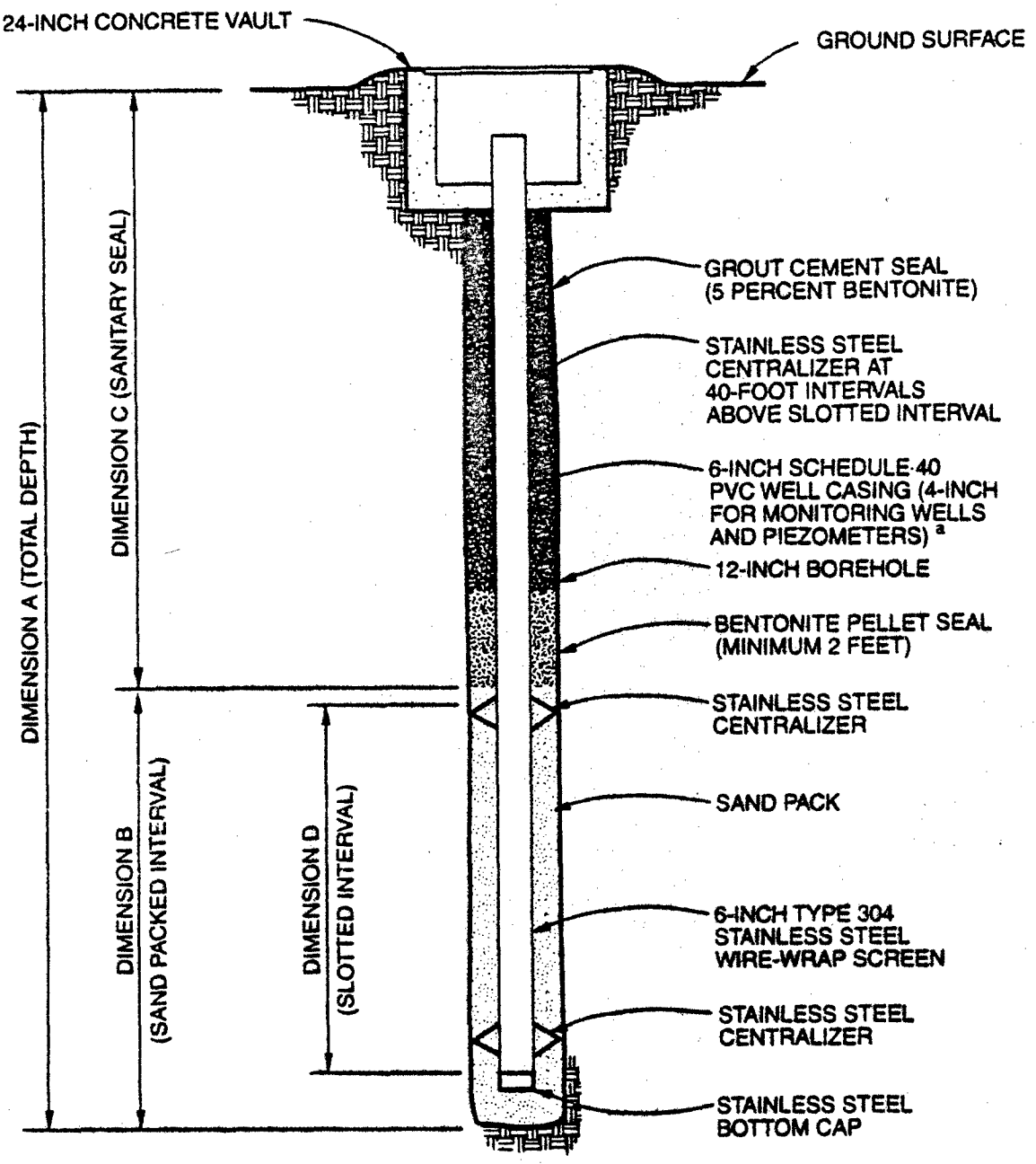
The extraction rates from each of the wells need to be measured regularly. Pumps should be selected that allow for variable flow rates. Flow rates may need to be adjusted to adopt to current hydrogeologic conditions during the life of the remediation.

Monitoring

Both water level and water quality data need to be collected once the system is operating. The water level data will be used to determine if groundwater within the target area is being hydraulically captured. The water quality data are necessary to characterize the influent mass contaminant loading to the treatment facility and the reduction in contaminants within the target areas. The frequency of water level measurements and water quality sampling will be specified in the waste discharge requirements. Recommended frequencies are provided below.

After the system is initially operated, all of the existing monitoring wells not being used for extraction and any additional water level measuring points should be measured weekly for a period of 2 months before the data evaluation is performed. Water levels should be measured monthly after the initial 2 months and when the extraction rates are kept constant. Water levels should be measured weekly for 1 month after the extraction rates are adjusted significantly or when nearby agricultural wells begin or cease pumping.

Each of the extraction wells should be sampled monthly during the first quarter of operation. A composite sample from all extraction wells should also be collected if there is a centralized treatment facility rather than treatment at each wellhead. All samples should be analyzed for VOCs (EPA Method 8010/8020). After the initial quarter, samples should be collected quarterly and analyzed for VOCs. It is assumed



WELL	DIMENSION A (FEET)	DIMENSION B (FEET)	DIMENSION C (FEET)	DIMENSION D (FEET)
EW-4C	140	30	110	20
EW-1D	185	30	155	20
EW-2D	185	30	155	20
EW-3D	190	35	155	20
EW-1E	250	35	215	25
EW-2E	250	35	215	25
E1	250	30	220	20

NOTE:
[a] Well E1 is a 5-inch-diameter well. Actual well construction may vary depending on field conditions.

FIGURE J-17
SCHEMATIC OF EXTRACTION AND MONITORING WELL CONSTRUCTION
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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that existing monitoring wells at the site will continue to be sampled quarterly under the Groundwater Sampling and Analysis Program (GSAP). The six additional extraction wells should be added to the GSAP.

The performance of the extraction system will be evaluated by estimating if groundwater within the appropriate target area is captured horizontally and vertically. Horizontal groundwater capture will be evaluated by preparing contour maps of the groundwater elevation in the B, C, D, and E aquifers using all existing water level data. In addition, water levels at selected well pairs in the B, C, D, and E aquifers will be compared to determine if there is inward groundwater movement to the appropriate target area. Vertical groundwater capture from the E and D aquifers to the C aquifer will be evaluated by preparing contour maps of the groundwater elevation in the C, D, and E aquifers. In addition, water levels at selected well pairs will be compared to determine if there is upward groundwater movement from the E and D to the C aquifer throughout the target area.

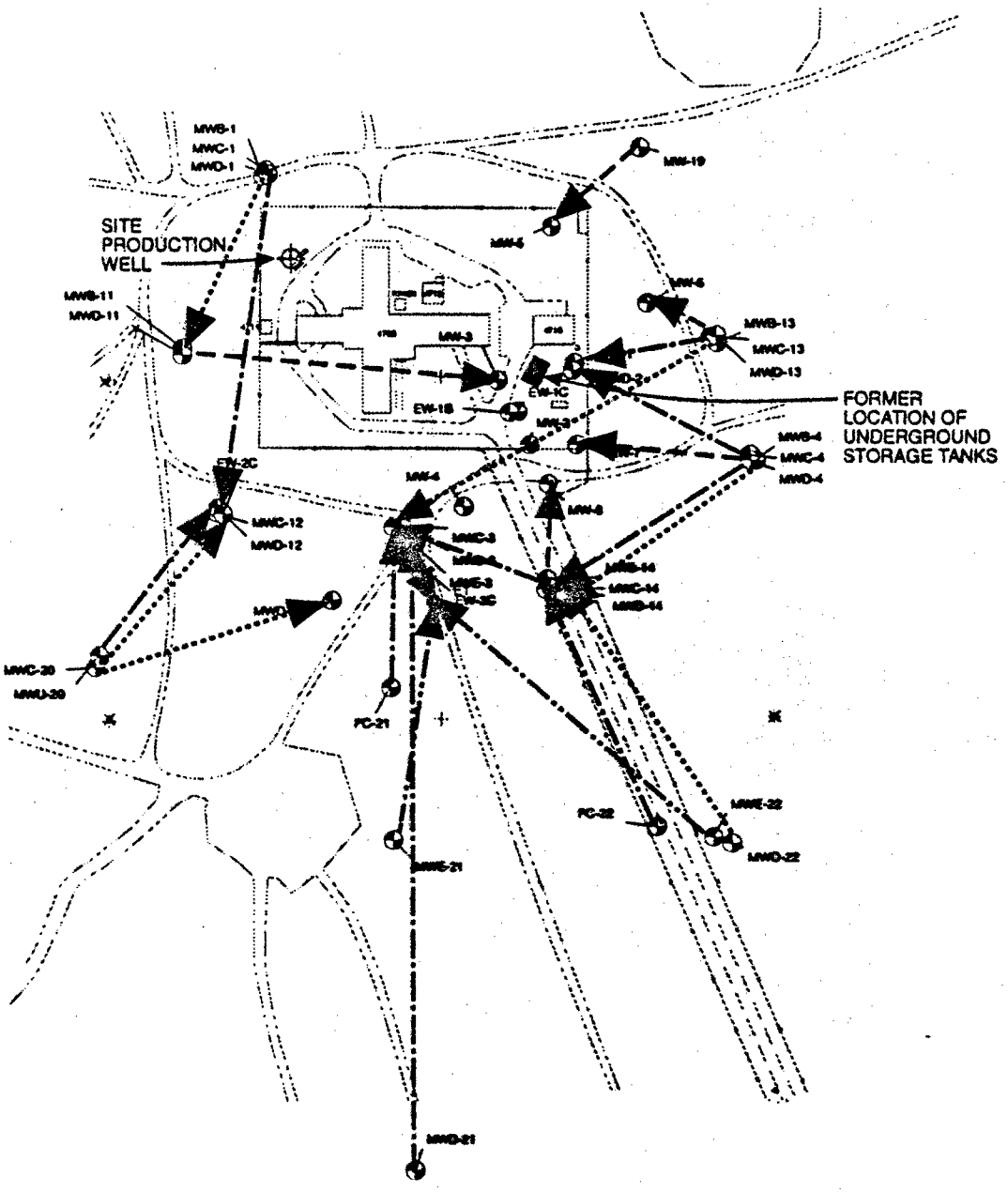
Table J-8 presents the recommended well pairs that should be used to help evaluate the system's performance for horizontal capture. Five B aquifer well pairs listed in Table J-8 will be used to evaluate horizontal capture of groundwater in the B aquifer. Eight C aquifer and seven D aquifer well pairs will be used to evaluate horizontal capture of groundwater in the C aquifer and D aquifer, respectively. Three E aquifer well pairs will be used to evaluate horizontal capture in the E aquifer if an additional monitoring point is installed in the location shown on Figure J-18. Vertical capture will be evaluated using eight well pairs in the C and D aquifers and two well pairs in the C and E aquifers. The groundwater movement should be upward from the E and D to the C aquifer.

Table J-8
Recommended Well Pairs for Monitoring Horizontal Capture (Summertime)
(Water level in first well should be higher than water level in second well)

B Aquifer		C Aquifer		D Aquifer		E Aquifer	
MW-19	MW-5	MWC-1	MWC-12	MWD-1	MWD-11	MWE-3	E1
MWB-4	MW-7	MWC-13	MWD-2	MWD-20	MWD-12	MWE-21	E1
MWB-13	MW-6	MWC-4	MWD-2	MWD-21	MWD-3	MWE-22	E1
MWB-11	MW-3	MWC-4	MWC-14	MWD-22	MWD-14		
MWB-14	MW-8	MWC-14	MWC-3	MWD-4	MWD-14		
		MWC-20	MWC-12	MWD-13	MWD-3		
		PC-21	MWC-3	MWD-20	MWD-10		
		PC-22	MWC-14				

Data Evaluation

The detailed schematic diagram of the extraction system operation shown in Figure J-19 illustrates the importance of data evaluation in meeting the management objectives of this intermediate remedial action. The operation of the treatment



LEGEND

- B Aquifer well pair
- C Aquifer well pair
- D Aquifer well pair
- E Aquifer well pair
- Groundwater monitoring well

N

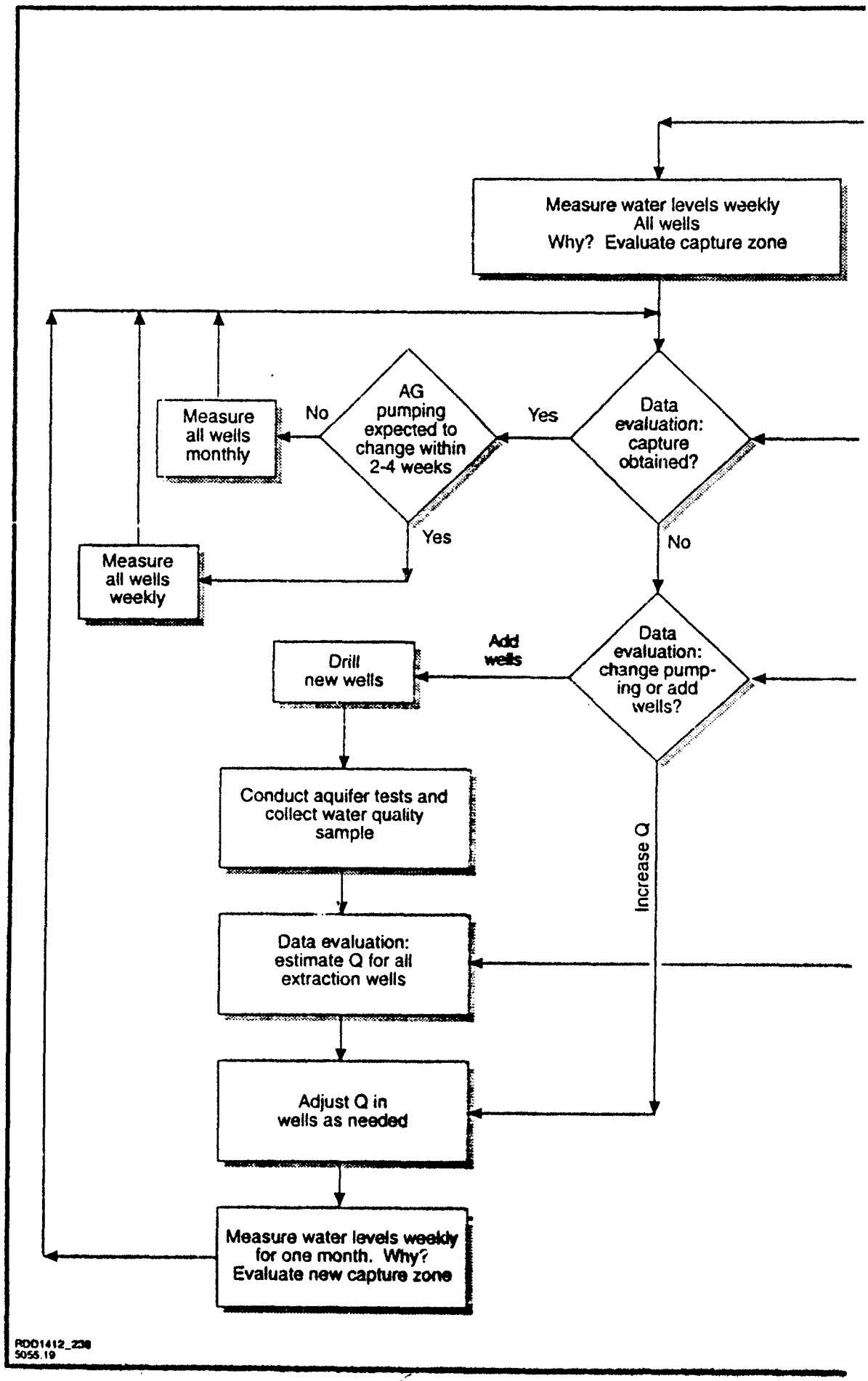
SCALE (Approximate)

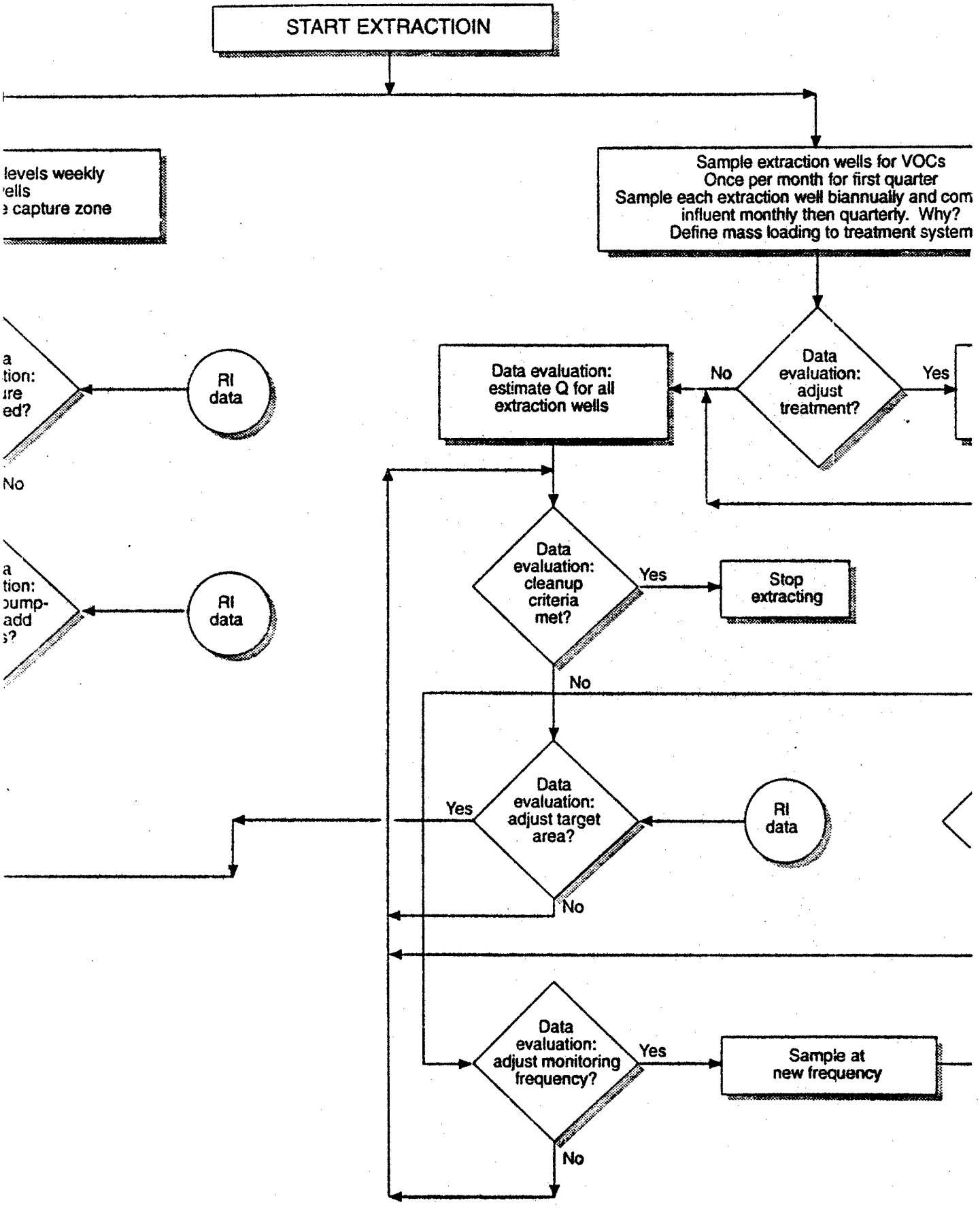
0 250 FEET

FIGURE J-18
RECOMMENDED MONITORING NETWORK
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

RDD1412_237
5055.19


Measure water levels weekly
All wells
Why? Evaluate capture zone
Data evaluation: capture obtained?
Yes
AG pumping expected to change within 2-4 weeks
No
Measure all wells monthly
Yes
Measure all wells weekly
No
Data evaluation: change pumping or add wells?
Add wells
Drill new wells
Increase Q
Conduct aquifer tests and collect water quality sample
Data evaluation: estimate Q for all extraction wells
Adjust Q in wells as needed
Measure water levels weekly for one month. Why? Evaluate new capture zone
RDD1412_238
5055.19


START EXTRACTIOIN
levels weekly
ells
capture zone
Sample extraction wells for VOCs
Once per month for first quarter
Sample each extraction well biannually and com
influent monthly then quarterly. Why?
Define mass loading to treatment system
a
tion:
ire
ed?
RI
data
No
Data
evaluation:
estimate Q for all
extraction wells
No
Data
evaluation:
adjust
treatment?
Yes
a
tion:
pump-
add
s?
RI
data
Data
evaluation:
cleanup
criteria
met?
Yes
Stop
extracting
No
Yes
Data
evaluation:
adjust target
area?
RI
data
No
Data
evaluation:
adjust monitoring
frequency?
Yes
Sample at
new frequency
No

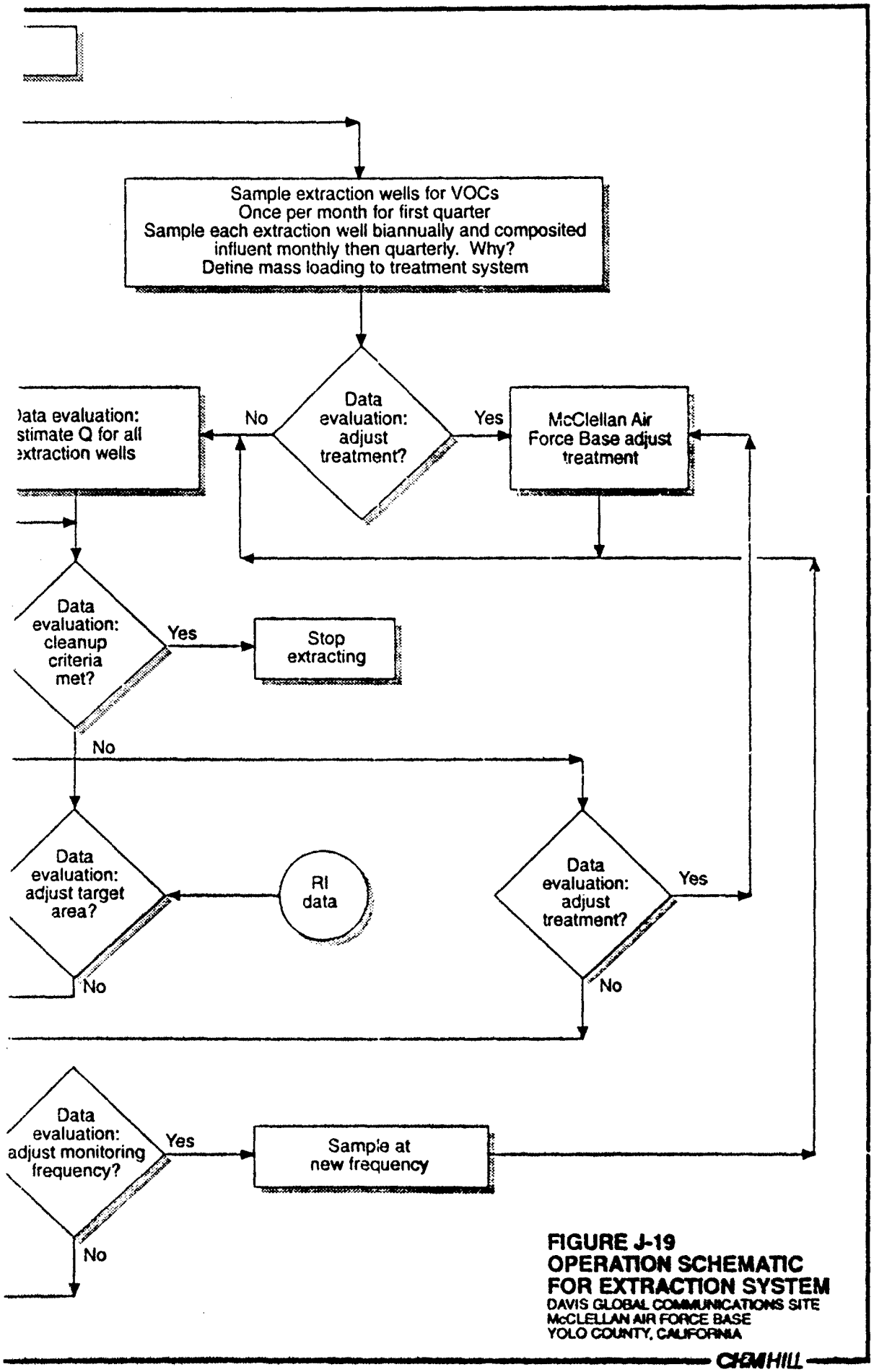


FIGURE J-19
OPERATION SCHEMATIC FOR EXTRACTION SYSTEM
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

facility and the end use may affect the extraction rates. For example, the extraction rates may need to be adjusted if the mass loading to the treatment system is too high. At a minimum, data evaluations will be performed monthly to determine if groundwater within the target area is being captured and to determine if the extraction rates should be adjusted. The analytical data will be evaluated at least quarterly to determine if the target area or treatment systems need to be adjusted.

Treatment Requirements

The estimated flow rates, initial influent concentrations, and initial mass loadings to the treatment system are provided in Table J-9. The mass loadings were estimated on the basis of analytical results for samples collected in February 1993 and use of the larger flow rates presented in Table J-5. Actual influent concentrations and mass loading will not be known until the extraction wells are drilled and sampled, and final extraction rates are known.

Influent concentrations were estimated from data for monitoring wells near the proposed extraction well locations. The contaminant concentrations for the extraction wells given in Table J-9 were estimated from the nearest groundwater monitoring well.

The actual time required for aquifer remediation cannot be predicted with current information. However, it is anticipated that concentrations may decrease exponentially as shown in Figure J-20. The rate of exponential decrease is a function of chemical retardation, diffusion-limiting processes in the aquitards and aquifers, and preferential flow paths in the target areas. Figure J-20 presents two theoretical curves estimated assuming exponential decay with flushing factors of 0.2 and 0.6, which correspond to a range of soil properties (fine-grained to coarse-grained). The chemical retardation factor for TCE at the site was estimated to be 1.4 (ITC, 1992) and is incorporated in the theoretical curves below. It is by no means certain that aquifer cleanup will be rapid; it should be expected that the extraction and treatment system will be in operation for a minimum of 10 to 20 years.

The effluent concentration of all VOCs is required to be less than 0.5 μg/l. The Regional Water Quality Control Board and Department of Toxic Substances Control recommend that for groundwater reinjection the effluent concentration of inorganic constituents be similar to background concentrations. Available background water quality data are summarized in Appendix M.

Table J-9
Estimated Initial Mass Loadings to the Treatment System

	Well	EW-1B		EW-1C		EW-2C		EW-3C		EW-1D		EW-2D		EW-3D		EW-1E		EW-2E		
	Flow (gpm)	80		150		100		50		100		60		100		120		60		
Parameter		Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Concentration (µg/l)	Mass Loading (lb/day)	Total Mass Loadings (lb/day)
TCE		350	0.34	350	0.63	2.6	0.00	21	0.01	0.31	0.00	2.6	0.00	15	0.02	1.5	0.02	37	0.03	1.05
cis-1,2-DCE		410	0.39	410	0.74	0	0.00	0.72	0.00	0	0.00	0	0.00	0.68	0.00	0.5	0.00		0.00	1.13
1,1-DCE		49	0.05	49	0.09	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00		0.00	0.14
PCE		170	0.16	170	0.31	1.1	0.00	38	0.02	0	0.00	1.1	0.00	0.79	0.00	0	0.00		0.00	0.50
Vinyl Chloride		82	0.08	82	0.15	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.23
Benzene		0.94	0.00	0.94	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
Chloroform		0	0.00	0	0.00	0	0.00	1.4	0.00	1.4	0.00	0	0.00	0	0.00	1.4	0.00	0	0.00	0.00
Methyl Chloride		0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1.7	0.00	0	0.00	0	0.00	0.00
1,1 DCA		0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
Toluene		0	0.00	0	0.00	0.23	0.00	0	0.00	0	0.00	0.23	0.00	0	0.00	0	0.00	0	0.00	0.00
Totals		1,061.94	1.02	1,061.94	1.92	3.93	0.00	61.12	0.03	1.71	0.00	3.93	0.00	18.17	0.02	14.9	0.02	37	0.03	3.05

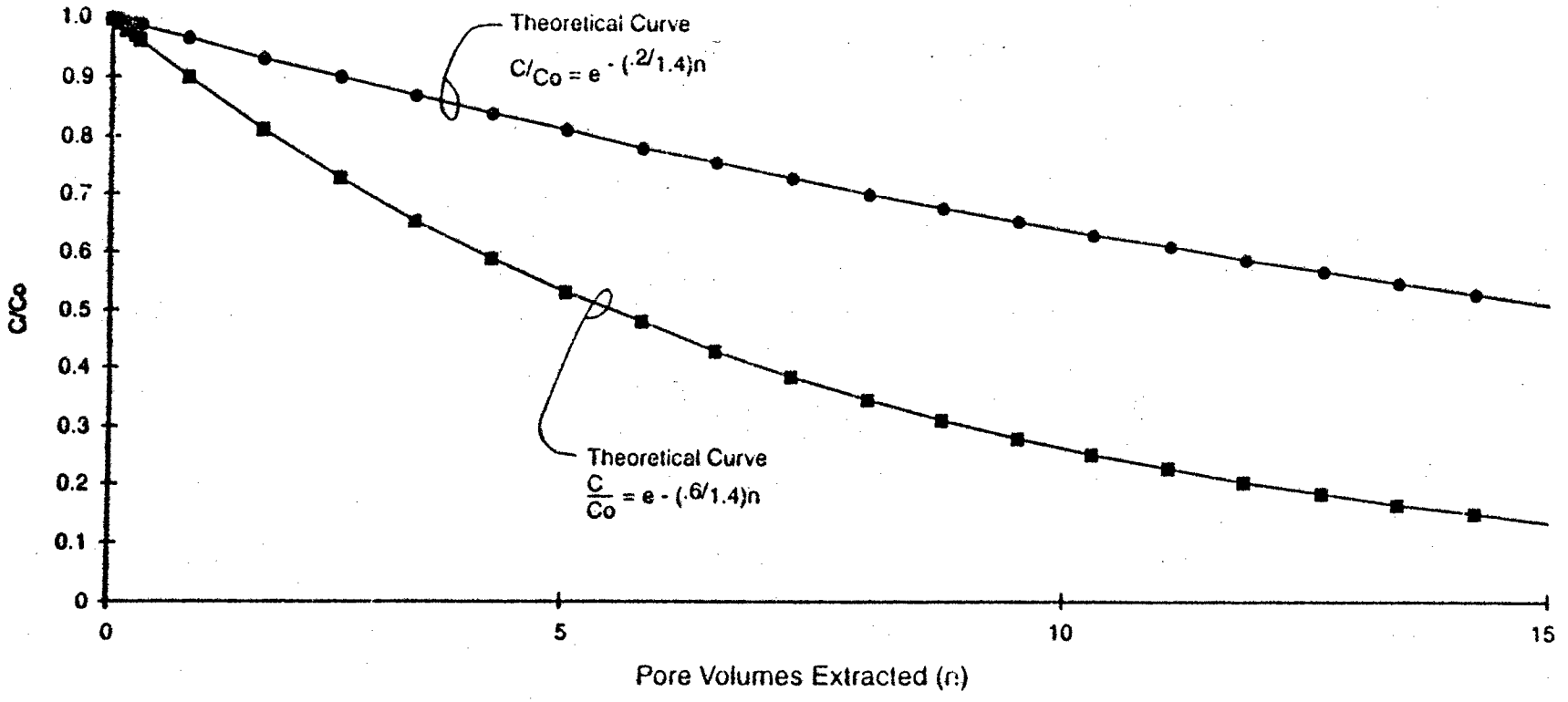


FIGURE J-20
ESTIMATED CHANGE IN
CONCENTRATION IN INFLUENT VOC

Reinjection Limitations

To date, limited data are available on groundwater quality with regard to inorganic constituents. The geochemical considerations for treatment will be revised as more data become available. Treatment processes directly affect the quality of the extracted groundwater, especially with respect to dissolved oxygen and metals concentrations. The dissolved oxygen, and particularly metal precipitates, in the treated groundwater could present a potential for plugging the reinjection wells.

The potential problem constituents for reinjection are calcium, magnesium, silica, manganese, and iron. Treatment processes tend to elevate the pH of the extracted groundwater, causing precipitation of metals (iron and manganese) and of calcium carbonate. A provision in the treatment process should be made to accumulate any precipitates on a filter before reinjection into the native groundwater. If the pH of the reinjected water is stabilized at or near background levels (assumed to be 7.3 to 8.0); reaction between the reinjected and in situ groundwater and between the reinjected groundwater and the aquifer mineralogy should be minimized. The major ion chemistry of the in situ groundwater and the treated water should be characterized before any reinjection occurs. Once the ion chemistry is known, the precipitation reactions should be checked using a thermodynamic equilibrium model. The equilibrium modeling will identify compounds that have a tendency to precipitate under the proposed treatment processes and conditions. Recommendations can then be made to identify corrective measures for potential problem precipitates.

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Hemker, C. J., and H. van Elburg. *MicroFem User's Manual: MicroComputer MultiLayer Steady State Finite Element Ground Water Modeling*. Amsterdam, The Netherlands. 1988.

ITC. 1992. *Final Preliminary Groundwater Remedial Investigation Report for the Davis Global Communications Site*. McClellan Air Force Base, California.

Radian. Davis Site Letter Report, January - March 1993. May 1993.

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Alex Rafalovich/CH2M HILL, Redding
Sara Monteith/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Hydrocarbon Remediation Options
Davis Global Communications Site
Delivery Order 5055

PROJECT: SAC28722.55.13

Introduction

This technical memorandum summarizes the current understanding regarding the nature and extent of petroleum hydrocarbon contamination that exists at the Davis Global Communications Site (the Davis Site), along with possible methods that could be used to clean up the contamination. The objective of this technical memorandum is to provide McClellan Air Force Base and the regulatory agencies with a better understanding of the remediation options available to reduce the concentrations of hydrocarbons in soil at the Davis Site.

Specifically, this technical memorandum focuses on two different remediation options: (1) *bioventing*, where in situ, aerobic biodegradation of the contaminants is accelerated by managing the subsurface supply of oxygen, and (2) *excavation*, where the contaminated soil would be physically removed from the subsurface.

Other remedial actions will also be needed at the Davis Site to clean up volatile organic compounds (VOCs) from the vadose zone and groundwater. Potential actions to address these problems are evaluated in the main text of this report. The impacts that these other remedial actions may have on the petroleum hydrocarbon remediation options are also evaluated in this technical memorandum.

History and Extent of Contamination

The petroleum hydrocarbon contamination at the Davis Site was discharged to the soil from three 25,000-gallon underground fuel storage tanks (UFSTs) located in the

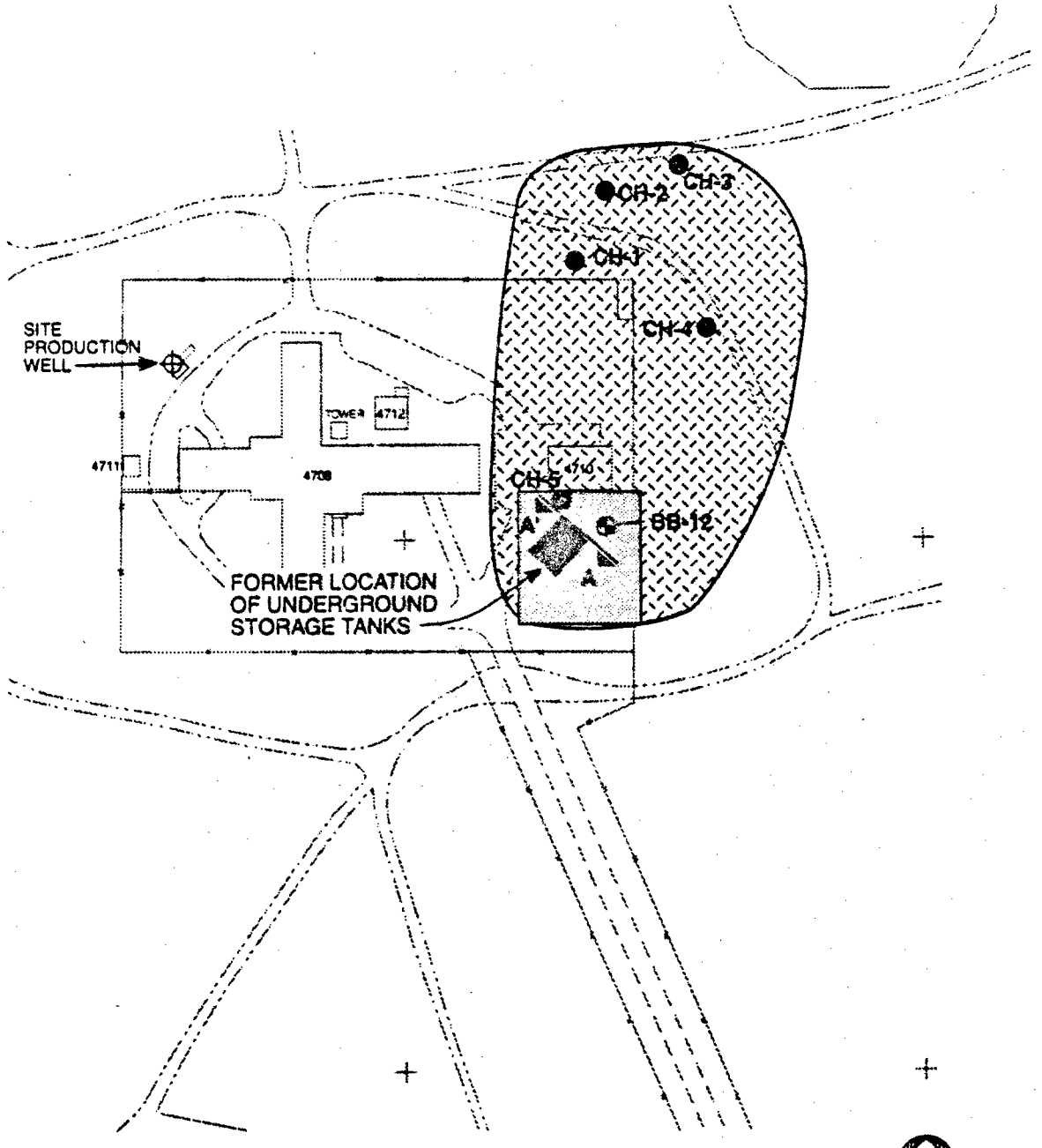
southeast quadrant of the site, just south of Building 4710 (Figure K-1). The UFSTs were used to store diesel fuel for the generator housed in Building 4710. In February 1985, approximately 52 cubic yards of soil overlying the UFSTs was removed and found to be saturated with petroleum product. The pipelines associated with the UFSTs were found to be leaking, and the exposed tanks showed deformation. In May 1985, a replacement 20,000-gallon above-ground tank was installed north of Building 4710, and the UFSTs were emptied. In December 1985, investigations revealed that soils adjacent to the UFSTs were contaminated with hydrocarbons. In May 1988, the UFSTs were removed, and the excavation was backfilled with clean soil.

Subsequent investigations have been performed by IT Corporation (ITC) and CH2M HILL to identify the extent of the petroleum hydrocarbon contamination. Figure K-1 shows the estimated lateral extent of the petroleum hydrocarbon contamination based on the results of these investigations. A cross section through the former tank storage area is presented in Figure K-2. Included in this figure are vertical profiles of petroleum hydrocarbon contamination based on samples collected from soil borings drilled in 1987 and 1992. Based on the figure, there are two primary zones of contamination in the vertical profile: one near 30 feet, and another near 60 feet below land surface (bls). Also, soil gas samples taken in 1992 from Well CH-5 at a depth interval of 28 to 38 feet show zero percent oxygen (O_2), 10 percent carbon dioxide (CO_2), and 2 percent methane (CH_4), indicating that the hydrocarbons at this depth have sustained aerobic and anaerobic degradation in the past, and that the contaminants currently reside in anaerobic conditions.

Ex Situ Soil Piles

Two areas of existing soil piles have been identified outside the Davis Main Compound southeast of Building 4710. The soil piles are believed to have originated during the removal of UFST's; however, the true origin is unknown. The soil piles have been identified as the northern pile and the eastern pile. These piles do not appear to have been disturbed since their placement; however, rodents and owls have been observed burrowing into them. The eastern and northern piles comprise approximately 560 and 320 cubic yards, respectively.

A total of 14 soil samples were collected in November 1992 from the soil piles, five from the north pile (NSP-1A, -1B, -2A, -2B, and -3) and nine from the east pile (ESP-1 through ESP-9). Samples were obtained using a hand auger to drill to 1 to 2 feet bls. The samples were analyzed for total petroleum hydrocarbon contamination using EPA 8015 Modified and EPA 418.1 methods. Levels of diesel contamination ranged from nondetect to 586 mg/kg. Results are presented in Appendix U, Historical Contaminant Data.



LEGEND

CH-2 ● SOIL VAPOR MONITORING WELL

BB-12 ◔ SOIL BORING

AREA OF VADOSE ZONE SOIL GAS CONTAMINATION

AREA OF PETROLEUM HYDROCARBON CONTAMINATION

FIGURE K-1
LOCATION OF PETROLEUM HYDROCARBON CONTAMINAT
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CHMHILL

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5056 19

A Risk Analysis performed by CH2M ... concurrent with this report reveals that the soil piles do not pose a significant risk to human health or the environment. Currently, the piles are inhabited by ... s and Borrowing Owls. Disturbance to the piles to expedite aeration would cause more harm than good to the burrowing animals. Therefore, options for ... e remediation of soil piles were not investigated.

Current Activities

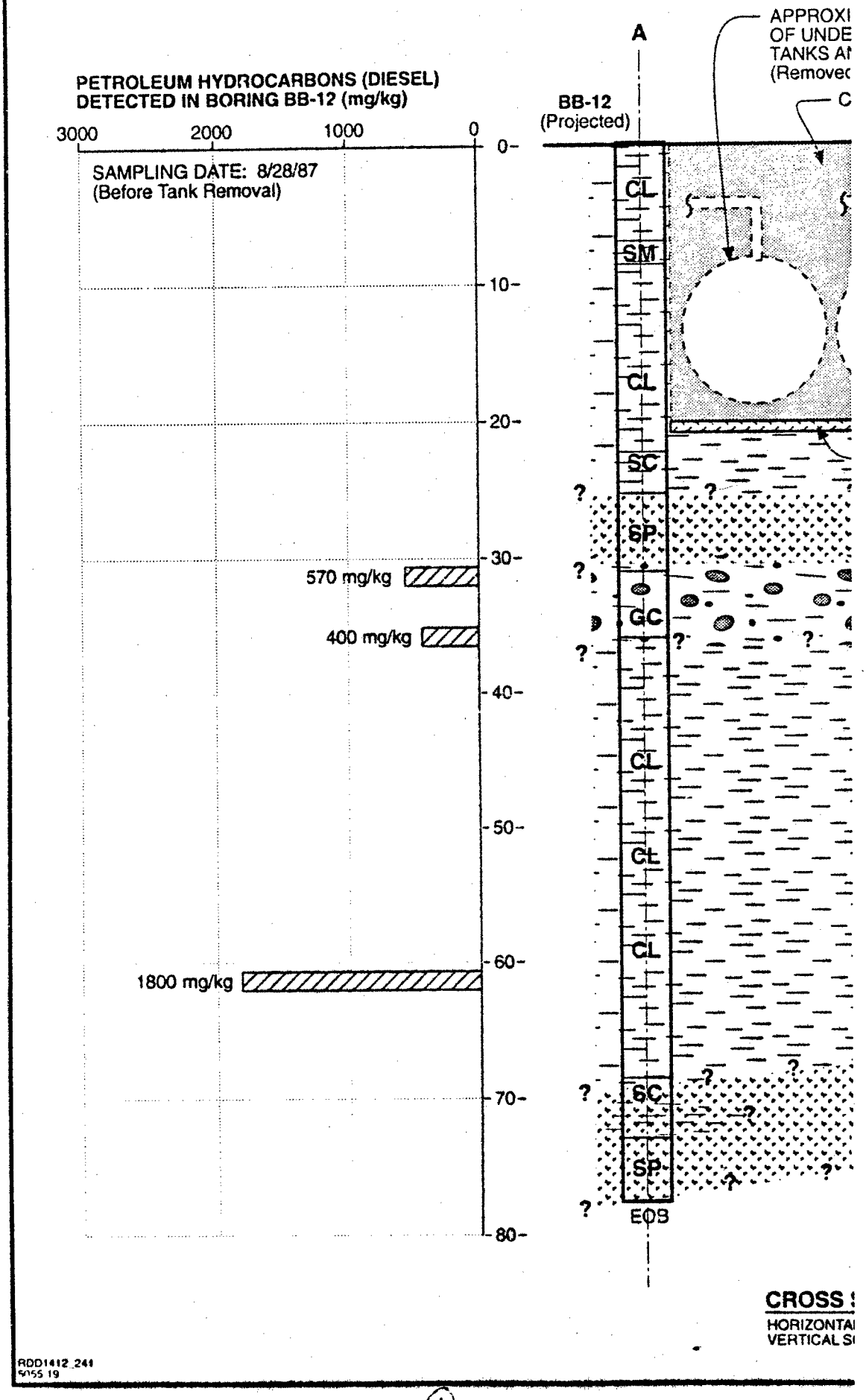
A bioventing treatability study is being conducted by Engineering-Science, Inc. (ESI) (ESI, 1993). The work is scheduled to be completed in September 1994. The work will include the following:

- Air permeability testing to determine the extent of the subsurface that can be oxygenated using one air injection unit
- In situ respiration tests to estimate the rate at which soil bacteria biodegrade the hydrocarbons
- Operation of a bioventing pilot test system over an extended 1-year period to help assess the potential long-term effectiveness of a bioventing system at eliminating the petroleum hydrocarbon problem from the Davis Site

The data from this treatability study will be assessed to determine if a full-scale bioventing program will be adequate to clean up these soils. Refer to the ESI Draft Bioventing Pilot Test Work Plan (May 1993) for more details on the plans for the bioventing treatability study.

Description of Cleanup Options

There are two fundamental options evaluated in this appendix for cleaning up the petroleum hydrocarbon contamination: bioventing and excavation. A detailed assessment of the bioventing option at the Davis Site cannot be performed until the treatability data from the study being conducted by ESI become available. Since this information is not available at this time, the evaluation of bioventing in this appendix relies on general assumptions from historical information regarding the effectiveness of bioventing systems at remediating diesel-contaminated soils. The bioventing evaluation presented here will provide for a useful comparison with the excavation option, but may need to be updated after the treatability study has been completed.


PETROLEUM HYDROCARBONS (DIESEL)
DETECTED IN BORING BB-12 (mg/kg)
3000
2000
1000
0
SAMPLING DATE: 8/28/87
(Before Tank Removal)
570 mg/kg
400 mg/kg
1800 mg/kg
0
10
20
30
40
50
60
70
80
BB-12
(Projected)
A
APPROXI
OF UNDE
TANKS AI
(Removec
C
CL
SM
CL
SC
SP
GC
CL
CL
CL
SC
SP
EOB
CROSS
HORIZONTA
VERTICAL S
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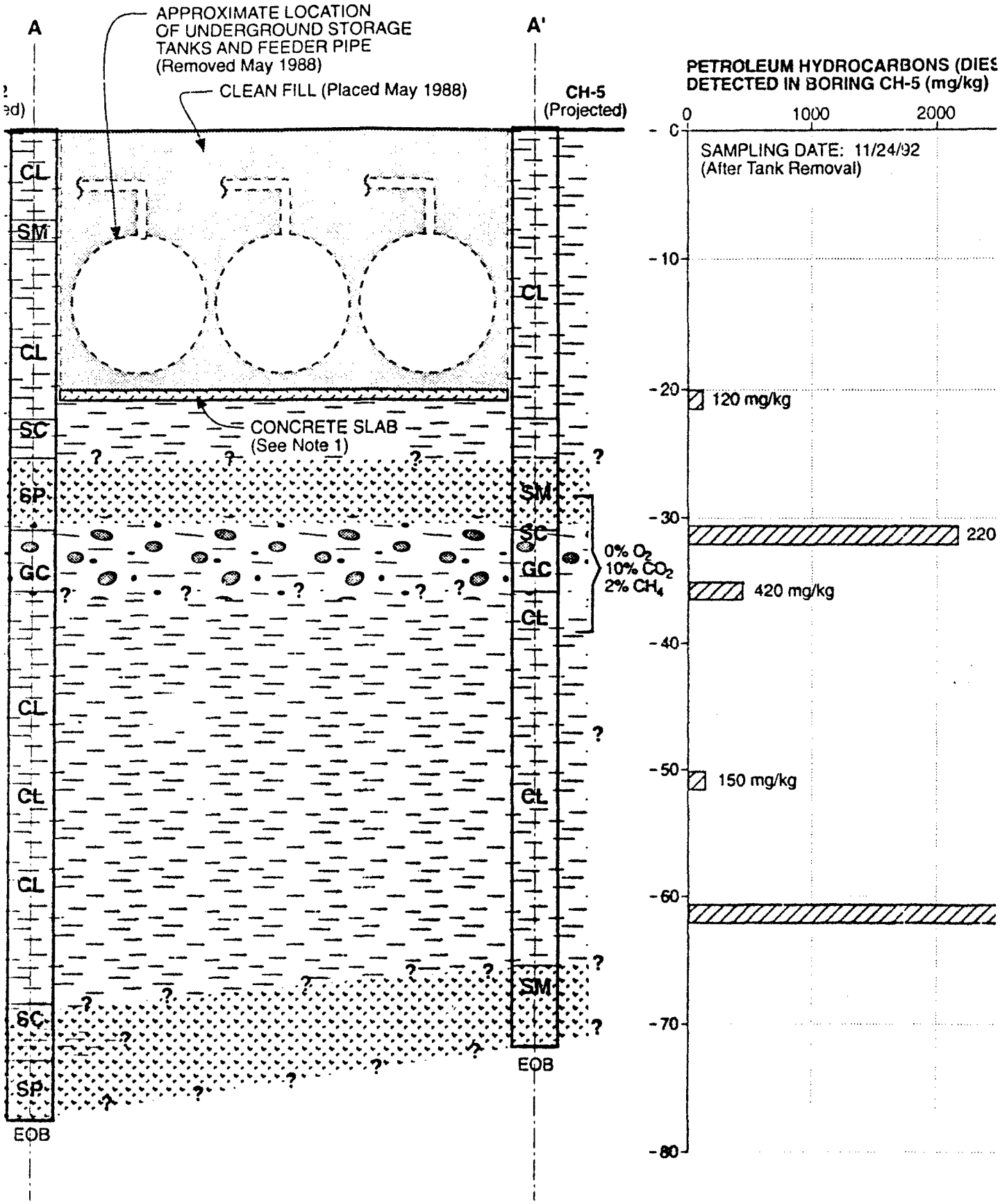


CROSS SECTION A-A'

HORIZONTAL SCALE: 1" = 10'
VERTICAL SCALE: 1" = 10'

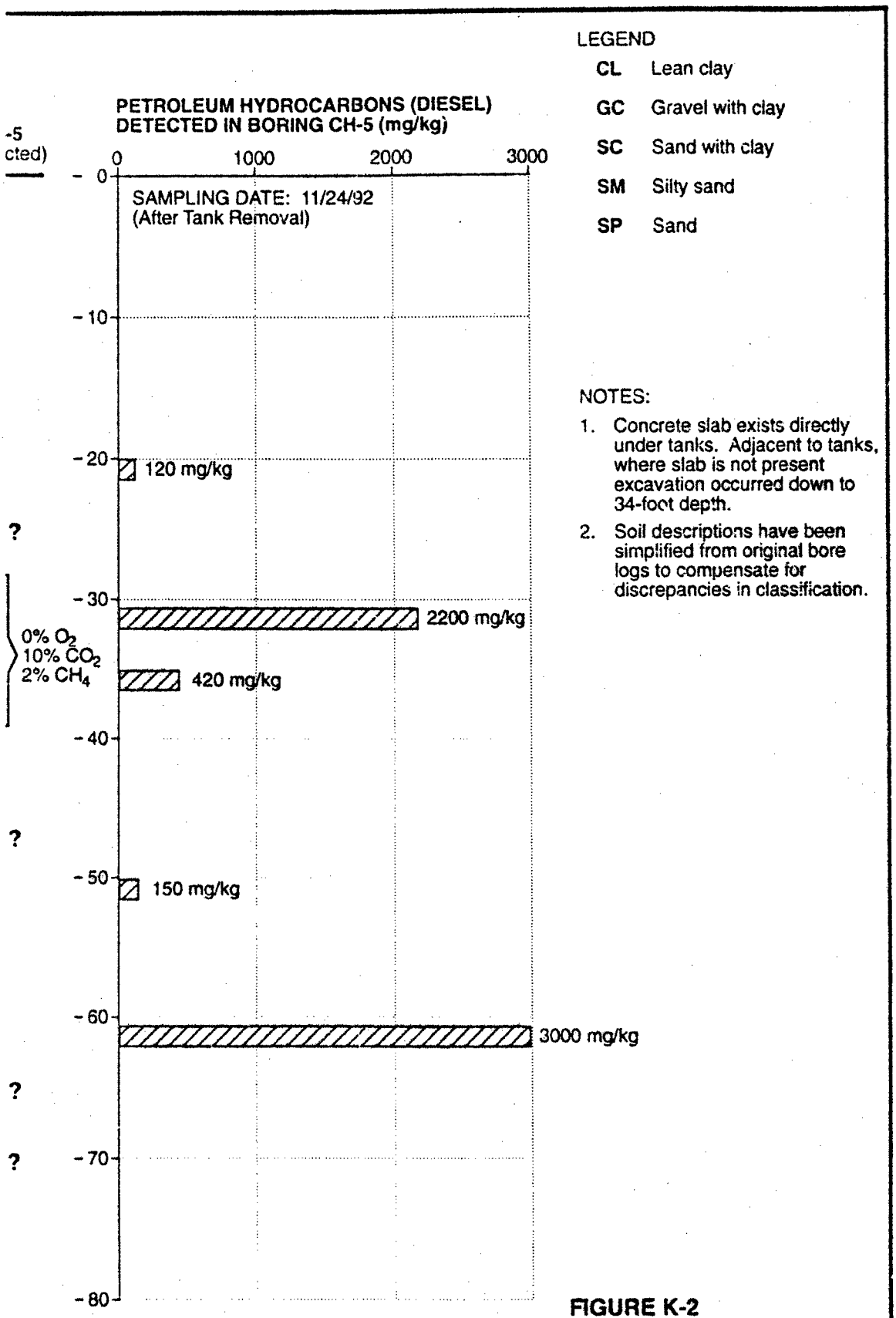


FIGURE K-2
CROSS SECTION OF FORMER UNDERGROUND STORAGE TANK AREA
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

CH2MHILL

Bioventing

Figure K-3 shows the layout proposed by ESI for the pilot-scale bioventing study. The configuration of the full-scale system will likely be similar to the pilot layout, with the potential for some modifications based on the treatability data generated from the pilot-scale study. The vent well (VW-1) will be an air injection well constructed of 4-inch ID Schedule 40 PVC casing with an interval of 0.04-inch slotted screen set between the initially encountered contamination (approximately 20 feet bls) down to the base of contamination (approximately 60 feet deep). The vapor monitoring points (VMP-1 and VMP-2) are multi-completion wells designed to monitor the vertical variation of oxygen, carbon dioxide, and methane to help estimate the rate of biodegradation of the diesel fuel. The existing soil vapor monitoring well, CH-5, will also be used as a monitoring point for the bioventing program. The reader is referred to the ESI Work Plan for more detail on the system construction (ESI, 1993).

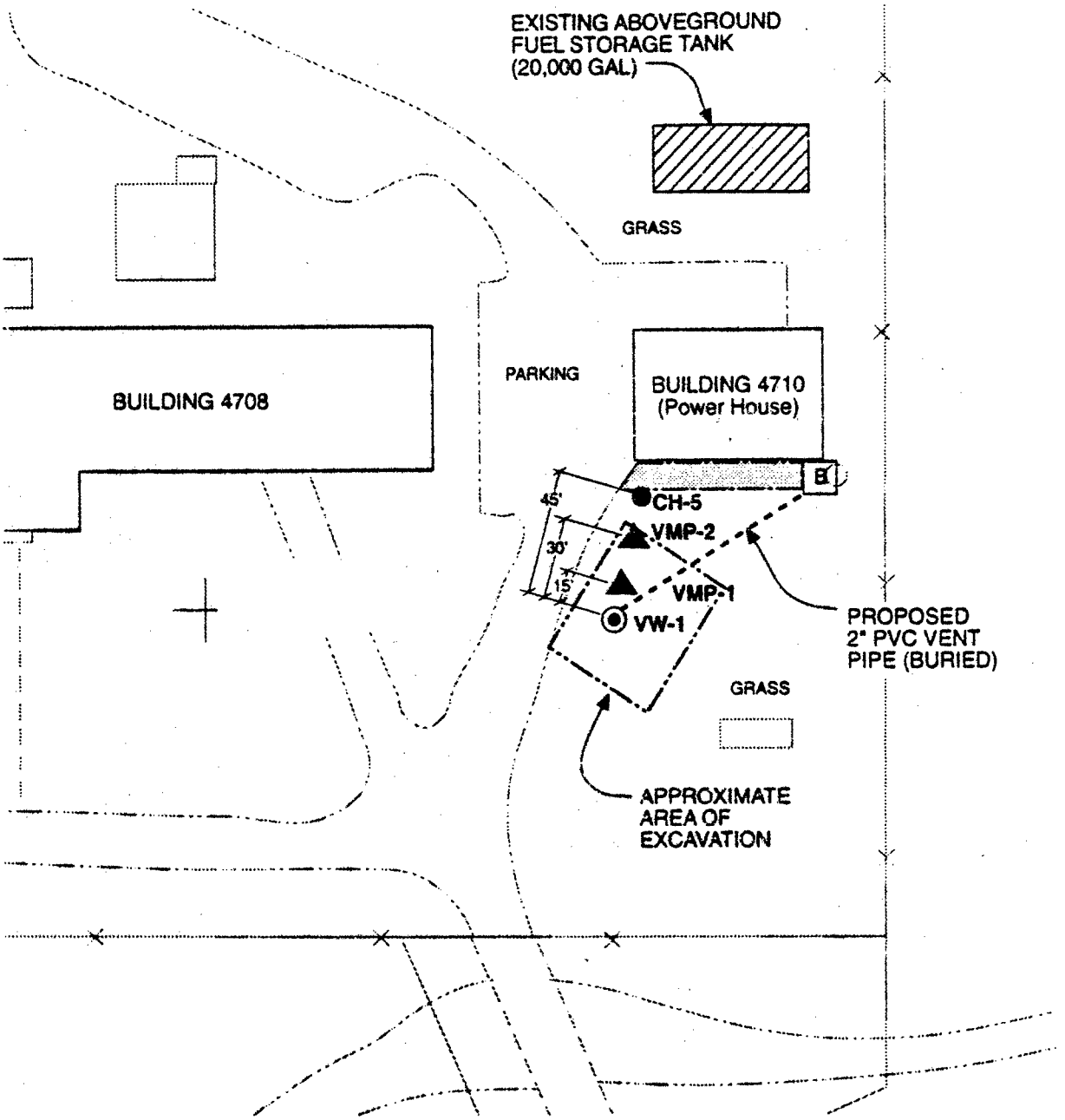
The bioventing project would be run using an appropriately sized blower to continuously inject air through Well VW-1. The size of the blower will be determined after the pilot-scale testing has been completed. In situ respiration tests will be conducted on at least a semi-annual basis to estimate the rate of biodegradation of the diesel fuel. These tests will involve shutting off the air injection blower and monitoring the rate of oxygen depletion and carbon dioxide generation at the vapor monitoring points. This data can then be used to estimate biodegradation rates (Hinchee and Ong, 1992).

The rate of biodegradation that will occur during a bioventing operation cannot be estimated at the Davis Site until the pilot-test treatability data are in. However, historical experience at other sites with diesel fuel contamination has shown biodegradation rates ranging anywhere from 0.2 to 20 mg/kg/day (Hinchee and Ong, 1992). The cost of implementing a full-scale bioventing program is also difficult to accurately estimate at this time. Previous experience indicates costs ranging from $10 to $20 per cubic yard of contaminated soil. The Davis Site has approximately 7,000 to 9,000 cubic yards of soil contaminated with diesel fuel, leading to a rough total cost estimate ranging from $70,000 to $180,000 to implement a full-scale bioventing system at the Davis Site.

Excavation

The excavation option can be divided into three components:

1. Excavation of contaminated soil
2. Hauling and placing contaminated soil
3. Placement of clean fill in excavation



LEGEND

- B — Proposed Blower Location
- CH-5 ● — Existing Vapor Extraction Well/Piezometers
- VW-1 ◉ — Proposed Vent Well
- VMP-1 ▲ — Proposed Vapor Monitoring Point
- ←—←—← — Fence

N

SCALE (Approximate)

0 50 FEET

FIGURE K-3
PROPOSED LAYOUT OF BIOVENTING PILOT TEST
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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CH2MHILL

The location of the area that most likely requires excavation is a square, approximately 120 feet per side (shown in Figure K-3). Based on available contamination data, the excavation should be approximately 60 feet deep. Given these dimensions, the amount of material to be excavated is approximately 32,000 cubic yards. It is believed that a concrete slab is located at a depth of 20 feet in the vicinity of the former tank location. Specialized excavation equipment may be required to break through and remove this slab.

Because this area has structures and roads nearby, it is assumed that the excavation will have vertical walls. The walls will be supported with H-piles "tied back" with anchors, and shoring between the piles. Existing underground utilities and structures would need to be located, and the design of the excavation should accommodate them.

It is anticipated that the excavation will extend approximately 20 feet below the groundwater table, and will therefore require construction dewatering for the deepest portions. (Depth to groundwater in this area is variable, but a depth of 40 feet below the ground surface is a reasonably average value.)

The excavation must be performed in accordance with state and federal safety guidelines, such as those provided by the Occupational Safety and Health Act, 29 CFR, Part 1926. In addition, because the material being removed from the excavation is considered to be hazardous, additional safety requirements may be imposed on this construction. It is likely that all workers will be required to have 40 hours of hazardous waste training, and that workers in the excavation will need respirators or supplied air.

For this estimate, it was assumed that the contaminated soil would be hauled and stockpiled onsite, and that remediation would be accomplished through aeration of the contaminated soil. A hauling distance of 1,000 feet was used for cost-estimating purposes. It was also assumed that the stockpiled soil would be no greater than 10 feet in height with 2:1 (horizontal:vertical) slopes. The area required for this stockpile would be a square approximately 320 feet per side.

The shoring and H-piles would be left in place when the excavation was backfilled, as there would be no way to safely remove them. If the excavation were no longer dewatered, crushed rock or some other material that does not require compaction should be used to bring the excavation above the water table. If dewatering continued during backfilling, any clean fill material could be used. Backfill should be placed using specified compaction requirements to minimize potential settlement.

It is estimated that the time required to complete excavating, hauling and placing, and refilling the excavation is approximately 6 months. During this time, the construction activities may adversely affect site operations or other remedial activities. The estimated cost of completing the excavation option, given the assumptions provided above, is approximately $2,846,000.

Comparison of Cleanup Options

The comparison between the bioventing and excavation options is done by describing how each option would likely perform with respect to nine evaluation criteria presented in EPA's guidance document for conducting feasibility studies (U.S. EPA, 1988). These nine criteria are:

1. **Overall Protection of Human Health and the Environment**—How will the two options offer long-term protection, and how are they different in achieving this level of protection?

2. **Compliance with ARARs**—How does each option comply with applicable or relevant and appropriate requirements (ARARs)?

3. **Long-Term Effectiveness and Permanence**—What would be the residual risks that remain after completing the remedial action?

4. **Reduction of Toxicity, Mobility, or Volume through Treatment**—This criterion addresses the statutory preference for using treatment as a means to permanently reduce toxicity, mobility, and volume. The question asked under this criterion is: How does each option use treatment to address the contamination?

5. **Short-Term Effectiveness**—What significant short-term impacts will the implementation of the cleanup options have at the site, including impacts to nearby communities and onsite workers?

6. **Implementability**—How easily can the cleanup option be implemented given technical and administrative constraints that exist at the site?

7. **Cost**—How much does the cleanup option cost?

8. **State Acceptance**—Will the state welcome the cleanup option?

9. **Community Acceptance**—What are the concerns that the public may have with respect to the cleanup option?

Table K-1 discusses the expected performance of bioventing and excavation with respect to each of these criteria.

Table K-1
Expected Performance of the Bioventing and Excavation Cleanup Options with Respect to EPA's Nine Evaluation Criteria

Criterion	Bioventing	Excavation
Overall Protection of Human Health and the Environment	By providing existing micro-organisms with an environment that allows them to break down the contamination, bioventing could virtually eliminate the threats posed by the contamination. However, treatability data still need to be obtained to demonstrate that bioventing can work at the Davis Site within an acceptable time frame.	By physically removing the contaminated soil from the subsurface, the threat posed to the groundwater resource would be eliminated. However, new threats may arise depending on how the contaminated soil is handled. If it is allowed to aerate in piles onsite, access will need to be restricted to minimize exposure of humans and animals to the soil.
Compliance with ARARs	Bioventing will only be implemented if the treatability data indicate that it can comply with all chemical-specific ARARs. The bioventing system would be designed to comply with all location- and action-specific ARARs. No waivers are anticipated.	An excavation option would be designed to comply with all ARARs. It is not known what ARARs may be associated with the placement of clean fill material below the groundwater table. Because the excavation option does not appear feasible from a cost perspective, the ARARS were not investigated.
Long-Term Effectiveness and Permanence	Bioventing may biodegrade up to 90 percent of the total in situ mass of diesel fuel. This may leave 10 percent of the mass still in the ground. Treatability data will be used to more accurately estimate the expected percent degradation at the Davis Site. A full-scale bioventing system would only be implemented if the estimated risk posed by this residual contamination is low enough to be acceptable to the regulatory agencies.	Excavation could potentially remove nearly all of the subsurface contamination. There may still be residual risks associated with the excavated soil, in particular if the soil is allowed to aerate in piles onsite. Most residual risks would be minimized by handling and transporting the soil in compliance with all ARARs. Risks related to the stability of the stockpiled soil would be minimized though design.
Reduction of Toxicity, Mobility, and Volume through Treatment	Bioventing satisfies the statutory preference for reducing toxicity, mobility, and volume through treatment, since the contamination is essentially subject to "biotreatment," where the contamination is rendered less toxic, less mobile, and occupies less volume due to biodegradation.	Treatment is not a part of the excavation option discussed in this document. No toxicity, mobility, or volume reductions would occur through treatment.
Short-Term Effectiveness	The wells used for the pilot study would also be used for the full-scale system, minimizing the need for additional construction. Some noise may be generated by the continuous operation of the blower unit, but this impact is not expected to be significant.	Significant short-term impacts would be created by the excavation option. The excavation require large earthwork equipment on site for up to 6 months. This work would have the potential to interfere with other onsite activities. In addition, a large 60-foot-deep hole would be created temporarily onsite during the removal of the contaminated soil.
Implementability	The technology is readily available to implement bioventing. In addition, the substantive portions of any permitting requirements can be met. The real question is: Given the conditions at the Davis Site, can the bioventing technology be effective at treating the diesel fuel? The answer to this question will not be known until the treatability study is completed.	The excavation option would be very challenging to implement at the Davis Site. The excavation would be deep (60 feet or more), and would inevitably require shoring. In addition, the excavation would need to occur adjacent to or extend under Building 4710, thus requiring extra caution to avoid building damage. Dewatering of the excavation will be needed. All of these problems can be addressed, and excavation is technically implementable, but with high effort and corresponding cost, especially when compared to a bioventing system that works.

Table K-1 Expected Performance of the Bioventing and Excavation Cleanup Options with Respect to EPA's Nine Evaluation Criteria		
Criterion	**Bioventing**	**Excavation**
Cost	Based on historic costs ranging from $10 to $20 per cubic yard, the bioventing option would cost between $70,000 and $180,000.	Estimated excavation costs is $2,850,000 for the Davis Site.
State Acceptance	Before a full-scale bioventing system is implemented, the state's approval would be obtained. State approval of this system will be contingent on the results of the treatability study.	At this time, no impediments have been identified to obtaining state approval for the excavation option.
Community Acceptance	Community acceptance of a bioventing system would also likely depend on the results of the treatability study.	Community acceptance of the excavation option is uncertain at this time, and will be more well defined after the public comment period for this RI/FS report.

Impact of Other Remedial Activities on the Cleanup Options

Other remedial actions are being considered at the Davis Site to clean up groundwater using *pump and treat* technology, and to clean up VOCs from the vadose zone using *soil vapor extraction*. These remedial activities may impact to some extent the petroleum hydrocarbon remedial action. These potential impacts are summarized in matrix form in Table K-2.

Summary

Bioventing and excavation were considered as the two possible methods for cleaning up the petroleum hydrocarbon contamination at the Davis Site. A full evaluation of bioventing cannot be completed until data from the bioventing treatability study being performed by ESI, have been analyzed. However, historical data for similar contaminant and soil types indicate that bioventing may be a very promising cleanup option. The excavation cleanup option would be costly and difficult to implement at the Davis Site because of the extreme depth of excavation required and the close proximity of buildings to the excavation site.

Other remedial actions are being considered at the Davis Site to address VOC contamination in the vadose zone and groundwater. There will inevitably be interactions between these remedial actions and the petroleum hydrocarbon remedial action. Careful planning during the remedial design/remedial action stage at the Davis Site is therefore necessary to coordinate all of these different remedial actions.

Table K-2
Impact of Groundwater and Vadose Zone Actions on Petroleum Hydrocarbon Cleanup Options

Groundwater/Vadose Zone Action	Impact of Action on Petroleum Hydrocarbon Cleanup Options	
	Bioventing	**Excavation**
Groundwater Pump and Treat	Pumping of groundwater may lower the water table, increasing the vertical depth over which bioventing can occur. Also, pumping may decrease the magnitude of water table fluctuation over a year. Personnel operating bioventing system may need to be trained in safety issues associated with the nearby operation of groundwater pump and treat equipment.	Excavation equipment would need to be handled carefully to avoid damaging any of the pump and treat equipment (e.g., wells, conveyance lines, treatment plants). Personnel operating and overseeing the excavation may need to be trained in safety issues associated with nearby operation of groundwater pump and treat equipment. Ideally, the excavation would be completed before beginning the pump and treat system.
Soil Vapor Extraction (SVE)	A soil vapor extraction system may impact the airflow direction and magnitude within the area of diesel fuel contamination. This could be a net benefit, if the oxygen supplied by the SVE system is high enough to eliminate or reduce the need for a separate blower for the bioventing system. Airflow modeling should be performed to assess the adequacy of the air flow induced by the SVE system for the bioventing site. In situ respiration testing may require the SVE system be shut off to obtain reliable oxygen depletion estimates.	Excavation equipment would need to be handled carefully to avoid damaging any of the soil vapor extraction equipment (e.g., wells, conveyance lines, treatment plants). Personnel operating and overseeing the excavation may need to be trained in safety issues associated with nearby operation of SVE equipment. Ideally, the excavation would be completed before beginning the SVE system.

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SUBJECT: SVE Gas and Stripper Offgas Treatment Evaluation
Davis Globai Communications Site
Delivery Order 5055

SUBJECT: SAC28722.55.13

Purpose and Scope

Cleanup options are being considered at the Davis site to remove subsurface VOC contamination from the vadose zone and groundwater. Contaminated air streams may be generated as a result of implementing these cleanup options: A *soil vapor extraction* system will inevitably generate contaminated gas; additionally, contaminated offgases may be generated from an *air stripper* that is designed to clean the groundwater. These air streams will require treatment to remove the contaminants. This memo evaluates and compares possible options that could be used to treat the airstream.

Assumptions Used in the Offgas Treatment Evaluation

Vadose zone airflow modeling indicates that four soil vapor extraction wells pumping at an average flow rate of 50 scfm each are needed to capture and remove the VOC contamination from the vadose zone (refer to Appendix I). Air from the four extraction wells shall be manifolded to yield one vapor stream. The vapor stream is assumed to contain contaminants at the concentrations listed in Table L-1. These concentrations are based on the most recent sampling from vapor monitoring wells at the site. The flow rate of the combined stream is 4 x 50 = 200 scfm. Modeling performed in Appendix I suggests that the VOC contamination in the soil would probably be adequately cleaned up within a time frame of 10 years.

The flow rate could increase by an additional 5,000 scfm if an air stripper is selected as part of the groundwater treatment option. In addition, an air stripper system would probably be in operation for a period of time far greater than the 10 years estimated to cleanup the vadose zone (potential operation time up to 30 years). The

Table L-1 Soil Gas Characterization				
No.	Contaminant	Concentration/ Range (ppb)	Organic Mass Loading (lb/hr)	Comments
1	Chloroform	3.4 to 7	1.58E-5 to 3.25E-5	ND in Well CH-5
2	Trichloroethene	17 to 9,500	8.70E-5 to 4.86E-2	1,900 ppb in Well CH-4 19 ppb in Well CH-5
3	Tetrachloroethene	91 to 82,000	5.95E-5 to 5.35E-1	91 ppb in Well CH-5
4	Dichlorodifluoromethane	3.3 to 100	1.70E-5 to 5.15E-4	ND in Wells CH-2, -3, & -4 100 ppb in Well CH-5
5	Trichlorotrifluoroethane	13 to 1,000	9.50E-5 to 7.30E-3	1,000 ppb in Well CH-1 Low ppb in other wells
6	cis-1,2-Dichloroethene	4.6 to 320	1.92E-5 to 1.21E-3	320 ppb in Well CH-4 12 ppb in Well CH-5
7	1,1-Dichloroethene	720 to 2,600	2.73E-3 to 9.85E-3	ND in Well CH-5
8	1,2-Dichloroethane	0 to 2.1	0 to 8.10E-6	ND in Wells CH-1, -2, -3, & -5
9	1,1-Dichloroethane	4.4 to 28	1.70E-5 to 1.08E-4	ND in Well CH-2
10	Toluene	2 to 740	7.20E-6 to 2.66E-3	740 ppb in Well CH-4 ND in Well CH-5
11	Benzene	16 to 360	4.88E-5 to 1.10E-3	360 ppb in Well CH-5
12	1,1,1-Trichloroethane	67 to 180	3.48E-4 to 9.35E-4	ND in Well CH-5
13	Vinyl chloride	0 to 510	0 to 1.25E-3	ND in all wells except Well CH-5
14	Ethylbenzene	0 to 19	0 to 7.85E-5	ND in all wells except Well CH-5
15	Methane	15,000,000	9.35	ND in all wells except Well CH-5
ND = Nondetect				

evaluation of the treatment options will initially be based on the 200 scfm flow and 5-year operating period; offgas treatment costs will be scaled up appropriately to reflect the increased flow and operation time should an air stripper be used.

Technology Descriptions

There are four contaminated gas treatment technologies evaluated in this memo: (1) electron beam technology (EBT), (2) catalytic oxidation (CatOx), (3) gas phase carbon adsorption (GAC), and (4) synthetic resin adsorption (Purus). This section provides brief descriptions of each of these technologies.

Electron Beam Technology

Electron beam technology (EBT) has been extensively used in medical applications for over 50 years; however, its use as a remediation technology for organic contaminated gases is in its infancy. The gas stream to be remediated is subject to a ray or beam of electrons generated by an electron beam generator. The electrons release small but intensive quanta's or concentrated pockets of energy into the gas stream creating free radicals such as hydroxyl and hydrogen radicals. The free radicals initiate a series of chain oxidation reactions that oxidize the chlorinated and nonchlorinated compounds into their completely mineralized forms such as HCl, HF, CO_2, and NO_x. Intermediates such as phosgene may be generated in negligible concentrations as a result of irradiation.

Chemical oxidation reactions in the E-beam equipment take place at near ambient temperature and pressure. The limited literature search conducted did not reveal commercial installation of EBT units that treat contaminated gas streams. Results of bench-scale tests conducted on SVE gases with similar contaminants indicated that Destruction Removal Efficiencies (DREs) for most organic compounds (except Freon 113 and 1,1,1-TCA) ranged from 60 to 99 percent; most species were reduced to below detection limits. Overall DREs of 87 percent plus were achieved for nonmethane hydrocarbons. DREs for Freon 113 and 1,1,1-TCA were found to be significantly lower than overall DREs. Preliminary results show that with the use of promoters (oxidants) a substantial improvement in DREs was observed; however, the quantity of promoters to be used has not yet been optimized.

Catalytic Oxidation

The halogenated and nonhalogenated VOCs exiting the air-water separator can be catalytically oxidized to complete products of combustion, namely CO_2, H_2O, and HCl, in a catalytic oxidizer (CatOx). The SVE air stream flows from the positive displacement blowers to a burner, where it is heated to approximately 600°F. The airstream is then passed through a catalyst bed, which initiates, promotes, and accelerates VOC oxidation. The catalyst, without itself being altered, significantly reduces the oxidation activation energy, thus allowing the oxidation reaction to occur

at much lower temperatures than would be required with conventional thermal oxidation.

Since oxidation is an exothermic reaction, it heats up the exiting gases as well as the catalyst bed. The exhaust gas stream temperature from the catalytic oxidation chamber would be approximately 840°F. Natural gas flow rates will be controlled to limit catalyst bed temperatures to approximately 840°F to protect the catalyst from being sintered. Although oxidation system vendors guarantee only a standard 95 percent destruction efficiency for organic vapors, based on performance history for similar streams, the actual destruction efficiency is estimated to be over 99 percent.

One of the chief advantages of a CatOx system is that DREs of greater than 95 percent can be achieved for all the compounds of concern. A disadvantage is that CatOx systems including packed-bed and fluidized bed systems which generate CO_2, NO_x, and HCl. NO_x generation is an exponential function of temperature and becomes significant at temperatures higher than 1,800°F. Since catalytic oxidizers operate only at about 600°F to 900°F, NO_x generation would be negligible in this case. If a CatOx system is implemented at this site, HCl emissions from the unit are estimated at 0.48 lb/hr; this is significantly below the RCRA level of 4 lb/hr. Therefore, additional post-treatment such as scrubbing of the gases is not anticipated.

A shell and tube (or plate and frame) heat exchanger can be used to recover waste heat from CatOx systems. However, in this case, the flow rate is too low to warrant the use of a heat exchanger.

Gas Phase Carbon Adsorption

Activated carbon is the most popular conventional adsorbent for the removal of most organic vapors from the air. Carbon is used in two basic types of air purification systems, regenerative and nonregenerative. Regenerative refers to a process by which the adsorbed contaminants are removed from the activated carbon onsite, so that the carbon may be utilized over and over again as an adsorbent. If a system is nonregenerative, the carbon medium must be removed and discarded or sent to the factory for reactivation on a periodic basis, as the carbon becomes saturated with the adsorbed contaminants.

The SVE gas flow rate from this site is expected to be extremely low for onsite regenerative carbon adsorption process to be cost-effective. Therefore, it was not considered in this evaluation. The nonregenerative carbon adsorption process would have been cost-effective at this site; however, just as in the case of the Padre system, vinyl chloride and methane are poorly adsorbed by carbon. Therefore, the gases exiting the carbon system would have to be further treated by technologies such as catalytic oxidation to achieve DREs greater than 95 percent for vinyl chloride and methane.

Synthetic Resin Adsorption

The Purus PADRE (Purus Adsorption Desorption Remediation Equipment) process is essentially similar to a conventional carbon adsorption system with the exception that the adsorbing matrix can be conveniently and economically regenerated several times onsite. Additionally, the adsorption matrix has a relatively higher adsorption capacity and hydrophobicity.

Typically gases contaminated with organics are introduced into the Purus system through a series of proprietary synthetic resin beds. The organic contaminants are adsorbed on the beds, and the resulting contaminant lean gas (hereafter referred to as the primary effluent gas stream) is vented to the atmosphere. When the beds reach their maximum effective adsorption capacity, the gas stream is diverted, on an automatically pretimed basis, to a similar series of adsorption beds that are plumbed parallel to the saturated beds.

Meanwhile, the saturated offline beds are subjected to a desorption cycle. During this process the resin beds are heated to volatilize the adsorbed organic contaminants and thus regenerate the beds for reuse. The beds are heated by noncontact heat tracing cables evenly distributed within the bed supports. Approximately 7 to 16 bed volumes of an inert carrier gas (nitrogen) are recycled through the desorbing bed. Nitrogen serves as an inert carrier medium to hold and move the organic contaminants from the adsorbing medium and also cools the beds for the subsequent adsorption cycle. Upon completion of desorption, the beds are cooled to ambient temperature by noncontact heat exchanger coils that circulate a heat transfer fluid such as DOWTHERM. The heat transfer fluid is cooled in a noncontact fintube heat exchanger by an induced air fan.

The nitrogen gas saturated with organic contaminants is passed through a chiller condenser system where the gaseous contaminants are condensed out as liquids. The contaminant-lean nitrogen gas (hereafter refereed as the secondary effluent gas stream) is typically discharged to the atmosphere.

In the adsorption beds, a negligible quantity of halogenated compounds may hydrolyze in the presence of moisture to halogenated acids such as hydrochloric acid. The concentration of hydrochloric acid emitted as a result of hydrolysis has not been measured and is therefore unknown; however, reaction kinetics and process conditions at the site would not be conducive for the formation of appreciable quantities of the respective acids and would not be of concern in this case.

The adsorption resin is known to have very little affinity for vinyl chloride and methane; hence, as the bed comes in contact with other organic compounds, it will have a tendency to displace the vinyl chloride that it had already adsorbed and replace it with heavier molecular weight compounds such as 1,1,1-TCA. Therefore, the removal efficiency of the Purus system with respect to vinyl chloride and methane is expected to be relatively low and would therefore not be effectively treated. Hence, the effluent gas stream from the Purus system will have to be treated using oxidation

technologies, such as catalytic oxidation, to oxidize methane and vinyl chloride emissions.

Technology Evaluation

The technologies were evaluated based on 10 important criteria relevant to justify implementation of the technologies. These criteria are listed and described below:

Destruction Removal Efficiency (DRE)

DRE is the single most important characteristic of a remediation technology. It is typically expressed as a percentage and is computed as follows:

$$\frac{\left[\text{Mass of component in feed stream} - \text{Mass of component exiting stack}\right]}{\text{Mass of component in feed stream}} * 100$$

Operating Costs

The operating costs reflect the maintenance and reliability of a system. Operating costs are annual recurring costs and include all costs associated with day-to-day operation and routine and nonroutine maintenance of the unit. Components of the operating costs are:

- *Expendables*—cost of replacement materials, i.e., carbon for carbon adsorption, adsorption resin for Purus PADRE, and catalyst for catalytic oxidation.
- *Fuel and utilities*—cost of process water, cooling water, electricity, compressed air, and fuels.
- *Labor*—costs associated with the manual operation and maintenance of the unit.
- *Maintenance*—cost of maintenance, including cost of replacements parts for auxiliary equipment (such as compressors, fans, etc.).
- *Residuals disposal*—cost of disposal of residual contaminants such as condensed solvents (in the case of Purus), scrubber blowdown, etc.

Capital Costs

In order for a technology to be cost-effective, the capital and operating costs should be low. Capital costs included here are those costs associated with original equipment, including the cost of process control, and auxiliary units.

Status of Development

A system or technology's track record is usually reflected by the degree to which the remediation method is considered proven commercial technology. Innovative technologies obviously would not have a track record, and hence predicting their reliability and performance is difficult.

Feed Variability

Owing to the ambiguous characteristics of SVE gases, the system should possess the ability to respond to abrupt changes in flow and concentrations.

Problem Compounds

These are compounds for which the destruction/removal efficiencies achieved by the system do not meet the desired performance objectives.

Reliability

This term refers to the system's consistency and safety during operation. For instance, a system that needs frequent shutdowns cannot be considered reliable.

Durability

Refers to the typical useful life of a piece of equipment.

NO_x/CO_x Emissions

Refer to the additional NO_x and CO_x emissions associated with the application of the technology.

Residual Generation

Some technologies may remove, destroy, or contain the contaminants of concern, but, they may generate other unwanted residuals that will need eventual disposal.

Screening Methodology

The weighted sum method was used to screen the options. This method is a quantitative method for screening and ranking the remediation options. It provides a means of quantifying the important and relevant criteria to help evaluate cost-effective offgas remediation technologies. This method involved four steps:

- Listing of the most important criteria in terms of treatment effectiveness and costs.

- Assigning of weights (W) of 0 to 20 for each of the criteria in relation to its importance. For instance, the criterion "overall destruction efficiency" was considered very important by the technology selection task force, while "durability" was of relatively minor importance. Therefore, the former was given a weight of 20 and the latter was given a weight of 5.

- Ranking (R) of each technology (option) based on a scale of 0 to 10, against each criteria. The justification for the ranks was based on information compiled for each technology, as summarized in Table L-2.

- Finally, multiplying the rank of each option for a particular criteria by the weight of the criteria (WR). The option's overall rating was determined by each technology's weighted ranking (i.e., $\sum WR$) with the first rank being assigned to the technology that received the maximum weighted sum (i.e., ΣWR). The option ranking matrix is provided in Table L-3.

Results of Screening

DRE was considered to be the most important criterion for selecting the technology to be implemented onsite. Catalytic oxidation was clearly the best in this category with expected DREs for all compounds of concern at >99 percent.

While other technologies can achieve the same level of efficiency for most compounds, they have trouble with some compounds. For example, both carbon and Purus adsorption systems are relatively ineffective with respect to removal of methane and vinyl chloride.

Preliminary bench-scale results indicate that while EBT could successfully reduce most organic species to below detection levels, its DRE with respect to compounds like 1,1,1-TCA and Freon was less than 60 percent. However, with the use of promotors, the DRE for the above compounds was increased to over 98 percent. Since the efficiency of this technology with use of promotors has not yet been optimized, it was ranked close to but lower than catalytic oxidation in this category.

Table L-2
Technology Analysis Summary

Technology	DRE	Operating Cost ($/yr)	Capital Cost (one well)	Status of Development	Feed Variability	Problem Compounds	Reliability	Durability	NO_x/CO_x Emissions	Other Residuals
Purus Padre	99%+ (except for problem compounds)	• Electricity = 4,380 • Residuals disposal = 48,000 • Labor & Maintenance = 19,000 • Other = 10,620 • Total = 76,000 (Note: methane and vinyl chloride are not treated)	• Purus 146,000 • Miscellaneous = 14,600 @ 10% of capital • Total = 160,600	• Commercial units have been under operation since 1991. • BACT approved (except for problem compounds).	Can efficiently handle concentration and flow changes (up to 10% of the maximum).	Not recommended for removing/treating methane, vinyl chloride, and Freon-12 compounds. Negligible DREs expected with respect to the above.	• Reliability is relatively unknown. • Minimal operator assistance required (2 hr/week)	Commercial systems have been in operation since 1991. Except for the resin itself, other components are standard off-the-shelf units such as chillers, condensers, fans, etc., that have a fairly well established track record for reliability.	None	• Organic compounds will be condensed and collected as liquids that will need disposal as hazardous waste. • Vinyl chloride and methane would need additional treatment.
Carbon Adsorption	99%+ (except for problem compounds)	• Carbon = 3,000 • Electricity = 3,300 • Labor & Maintenance = 12,000 • Other = 2,900 • Total = 21,500 (Note: methane and vinyl chloride are not treated)	• Carbon = 18,000 • Miscellaneous = 1,800 @ 10% of capital • Total = 19,800	• Proven and well established technology • BACT approved (except for problem compounds)	Can fairly handle concentration and flow changes. Adsorption cycles are typicallly preset for a given concentration and flow condition.	Not recommended for removing/treating methane, vinyl chloride, and Freon-12 compounds. Negligible DREs expected with respect to the above.	• Extremely reliable with minimum shut-downs • Minimal operator assistance required (2 hr/week and 8 hours annually during carbon change-out)	System lifespan expected to adequately cover remediation duration	None	• Spent carbon needs replacement. • Typically, fresh carbon supplier takes spent carbon for regeneration. • Vinyl chloride and methane would need additional treatment

Table L-2
Technology Analysis Summary

Technology	DRE	Operating Cost ($/yr)	Capital Cost (one well)	Status of Development	Feed Variability	Problem Compounds	Reliability	Durability	NO_x/CO_x Emissions	Other Residuals
Catalytic Oxidation	99% + for all organic compounds of concern	• Catalyst = 2,000 • Electricity = 10,800 • Labor & Maintenance = 13,000 • Other = 3,200 • Total = 28,000 (Note: methane and vinyl chloride are completely destroyed)	• Catox = 61,000 • Miscellaneous = 6,000 @ 10% of capital • Total = 67,000	• Proven and well established technology • BACT approved for all compounds of concern	Can efficiently handle concentration and flow changes. The burner and dilution valves can be made to automatically adjust with feed variation.	None. All compounds of concern will be completely mineralized to basic oxidation products	• Reliability is fairly good requiring relatively few shutdowns • Minimal operator assistance required (2 hr/week)	System lifespan expected to adequately cover remediation duration	Unit will generate NO_x and CO_x	• HCl emissions are estimated at well below RCRA allowable emissions of 4 lb/hr • Potential for particulate emission from attrition of catalyst
Electron Beam Technology	98% + (except for problem compounds)	• Electricity = 14,000 • Consumables = 37,500 • Labor & Maintenance = 14,000 • Other = 13,500 • Total = 79,000 (Note: methane and vinyl chloride are treated)	• Capital cost = 60,000 • Miscellaneous = 6,000 @ 10% of capital • Total = 66,000	• Currently transitioning from bench to pilot scale • Not yet approved as BACT	Can efficiently treat over twice the concentration or flow levels	1,1,1-TCA and Freon-12 are problem compounds with DREs at less than 90%. However, with the use of promoters, DREs of 98% + may be expected.	Unknown since history of commercial scale units is not available.	Unknown	Unit will generate NO_x and CO_x	• HCl emissions are estimated at well below RCRA allowable emissions of 4 lb/hr • Potential for generation and release of small quantities of phosgene

BACT = Best Available Control Technology
DRE = Destruction Removal Efficiency

Table L-3 Option Ranking									
Technology	Weight (W)	Electron Beam Technology		Catalytic Oxidation		Carbon Adsorption		Purus PADRE	
		R	WR	R	WR	R	WR	R	WR
DRE	20	9	180	10	200	7	140	8	160
Operating Cost	15	3	45	8	120	10	150	3	45
Capital Cost	15	3	45	3	45	10	150	1	15
Status of Development	15	3	45	10	150	10	150	7	105
Feed Variability	5	6	30	10	50	6	30	6	30
Problem Compounds	10	8	80	10	100	2	20	4	40
Reliability	5	4	20	10	50	10	50	6	30
Durability	5	2	10	10	50	10	50	4	20
NO_x/CO_x Emissions	5	4	20	2	10	10	50	10	50
Other Residuals	5	4	20	4	20	5	25	3	15
Weighted Total	Weighted Sums ΣWR		495		795		815		510
Overall Ranking	Overall Technology Rank		4		2		1		3

The capital cost of carbon adsorption units ($19,800) was estimated to be the least expensive choice, followed by EBT ($66,000), CatOx ($67,000), and Purus PADRE ($160,600). The electron beam technology was estimated to have the highest operating cost ($79,000 per year); the high operating cost is attributed to the cost of promotor chemicals required to reduce the concentration of important chemicals such as 1,1,1-TCA and Freon 113 to the desired levels. Sufficient optimization of promotor dosages has not yet been completed; it is estimated that these dosages may significantly decrease as a result of additional process optimization related to the commercial-scale development of this technology. The operating costs for Purus PADRE and carbon adsorption systems were estimated to be $76,000 and $21,500 per year, respectively. The operating costs estimated for Purus and carbon do not reflect the additional costs that will be incurred to treat and reduce vinyl chloride and methane to the desired levels. The operating cost for the CatOx unit was estimated at $28,000/yr.

Status of development was given significant importance in selecting the technology because it was the best measure of the system's overall performance, including its track record for consistently achieving high desired DREs, providing relatively maintenance free and safe operating conditions. Additionally, it provides a wider choice of vendors to select from. Carbon adsorption and CatOx were ranked high in this category since these technologies are well established and have been around for several years. PADRE and EBT were given lower rankings for this category since they are fairly new applications.

Other criteria such as reliability, durability, residual compounds, NO_x, and CO_2 emissions were used to judge the appropriateness of the technology in the same manner; the results of the evaluation (see Table L-3) are based on the information provided in Table L-2.

Impacts on the Evaluation if an Air Stripper is Used

The offgas flow rate from the stripper is estimated at 5,000 scfm i.e., 25 times more than the flow rate of the SVE gas stream. The unit that is designed to handle the stripper offgas system will be adequate to handle the SVE gas stream. The characteristics of the stripper off-gas and the corresponding organic mass loading on the pollution control equipment that will be used to treat the gases are given in Table L-4.

Table L-4 Characteristics of Stripper Offgas		
Compound	Concentration (ppm)	Mass Loading (pph)
VC	0.175	0.009
PCE	0.144	0.021
TCE	0.362	0.041
cis-1,2-DCE	0.056	0.005
1,1-DCE	0.067	0.006
Total		0.062

The estimated concentrations of the organic compounds in the stripper offgas are relatively low. The control efficiency of adsorption technologies is not considered to be effective in the lower ppm range; catalytic oxidation is the only demonstrated technology that is considered to be relatively more effective in the lower ppm ranges. Yet another criterion in disfavor of adsorption systems is their relative ineffectiveness in containing or treating vinyl chloride. Electron beam technology as mentioned earlier can be an effective treatment technology but has not yet been demonstrated on a commercial scale.

The capital and installed costs of a catalytic oxidation unit capable of handling 5,000 scfm of the above gas stream are estimated at $450,000 and $700,000, respectively. The annual operating cost is estimated at $180,000/yr. The HCl, CO_2, and NO_x emissions generated from treating the SVE and stripper offgases are estimated at 0.54, 300, and 2 lb/hr, respectively.

Although the operating costs for catalytic oxidation systems is one of the lowest among the technologies evaluated, its relative consumption of energy (natural gas) at the site for treating a gas stream with a low contaminant concentration and high flow rate is relatively high. Additionally, oxidation of natural gas produces CO_2 and NO_x. Therefore, it is advised that other groundwater treatment technologies that do not transfer the contaminants, especially vinyl chloride, into the air be pursued.

Recommendations and Conclusions

Case 1: Treatment of SVE Gases (200 scfm) Only

Our research discovered only one vendor currently testing EBT for remediating contaminated gases. The operational and maintenance problems associated with this equipment are unknown due to lack of historical information on this system. Owing to lack of concrete evidence of the prototype's reliability and performance

characteristics (especially with respect to 1,1,1-TCA), this technology is not currently recommended for this site. This technology has great potential and is being vigorously pursued by its vendors to be prototyped and tested. Therefore, it may be reconsidered at the time of final selection of the remediation technology.

Since PADRE cannot be used as a stand alone technology, the overall capital and operating costs associated with achieving a DRE of +95 percent for all organic contaminants (i.e., including methane and vinyl chloride) would be exorbitant for remediating SVE gases at this particular site. Therefore, PADRE is not recommended.

Carbon adsorption suffers from the same problem as PADRE (i.e., vinyl chloride and methane would require additional treatment to reduce their concentrations by 95 percent plus). The necessity for additional equipment would render carbon adsorption unattractive for implementation at McClellan AFB.

CatOx units have been demonstrated successfully on similar streams and have proved that they can achieve over 99 percent DRE for all of the compounds of concern. Owing to its overriding advantage with respect to achieving high DREs, its relatively reasonable capital and O&M costs, and its established track record in terms of reliability and durability, this system is recommended for implementation at the site.

In this context, it is noted that except for Well 5, vinyl chloride and methane were conspicuously below detection levels in other wells. The methane presence could be attributed to the diesel contamination (in the Well 5 zone) which is typically a healthy environment for biological activity. Enhanced biological activity could also be the reason for the presence of some vinyl chloride that could be generated as a biological degradation product of other chlorinated solvents. Additionally, based on the historical information from other sites, vinyl chloride concentrations drop below detection limits with about 4 to 8 weeks of continuous extraction of SVE gases.

Given this scenario, a marginally more cost-effective approach would be to remediate offgases with a rental catalytic oxidation unit (at approximately $5,000/month for a 250-scfm unit) for a period of 2 months, and then replace the unit with a permanent carbon adsorption system. This approach, however, assumes that releasing methane (without treatment) to the environment is acceptable to regulatory agencies.

Case 2: Treatment of SVE Gases (200 scfm) and Stripper Offgas (5,000 scfm)

Given the potential for a continued presence of vinyl chloride (at a concentration level below what is observed now) in the stripper offgas, catalytic oxidation is the most suitable, effective, and demonstrated technology for this case. The HCl emissions from the CatOx unit are estimated at 0.54 lb/hr, which is lower than the RCRA allowed limit of 4 lb/hr. The additional CO_2 and NO_x emissions are estimated at 300 and 2 lb/hr, respectively.

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Michele Clark/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Groundwater Treatment Options
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.13

Purpose and Scope

The purpose of this technical memorandum is to set forth a preliminary description and evaluation of options for treatment of contaminated groundwater within the Davis Global Communications Site (Davis Site) in Sacramento, California. The treatment options considered include air stripping, liquid-phase carbon adsorption, and advanced ultraviolet (UV) oxidation.

Cost estimates for these technologies were developed and are also presented in this technical memorandum. The cost estimates have been developed to describe treatment plant installed capital costs and operation and maintenance (O&M) costs without projectwide contingencies. These estimates are intended to be assembled with other capital and O&M costs for other project components and adjusted with projectwide contingencies and allowances when assembled together. Detailed cost sheets are appended to this technical memorandum.

Background

During the remedial investigation of the Davis Site, the groundwater below the site was found to be contaminated with chlorinated volatile organic compounds (VOCs). Several aquifer zones were identified at the site as B, C, D, and E. The B aquifer is the shallowest aquifer. The D and E aquifers are considered regional aquifers because most of the agricultural pumping in the vicinity of the site draws water from these aquifers.

The two upper zones, the B and C aquifers, are the most contaminated In the D and E aquifers, only trichloroethene (TCE) had concentrations above the federal maximum contaminant levels (MCLs). The TCE concentrations were one order-of-magnitude greater than the MCLs. To prevent the highly contaminated groundwater

of the B and C aquifers from migrating downward or outward from the site, it will be extracted, treated, and sent to end-use. Two target volumes to be treated were evaluated for the treatment costs.

Groundwater Flows

The first target volume (TV 1) is the combined groundwater from the B and C aquifers. The second target volume (TV 2) is the combined flow of all the aquifers (B, C, D, and E). Table M(a)-1 presents the groundwater flows from the two target volumes.

Table M(a)-1
Treatment Plant Groundwater Flows

Target Volume	Aquifers	Flow (gpm)
1	Combined flow (B and C)	380
2	Combined flow (B, C, D, and E)	820

Since the contaminant concentrations in the D and E aquifers are minimal, they will not significantly increase the effort needed to remediate the B and C aquifers. However, the flow rate to the treatment system differs significantly between the two target volumes and will generate different treatment costs.

Groundwater Contaminant Concentrations and Treatment Goals

The treatment influent contaminant concentrations for each target volume are presented in Table M(a)-2. The main contaminants in regards to public health are TCE, tetrachloroethene (PCE), 1,1-dichloroethene (1,1-DCE), vinyl chloride (VCL), and cis-1,2-dichloroethene (cis-1,2-DCE). The treatment objective is to treat the groundwater concentrations of any individual VOC to less than or equal to 0.5 μg/l, which is defined as a nondetect concentration. Benzene has been detected at two wells within TV 2, but the expected influent concentration to the treatment plant is well below the treatment objective.

The concentrations are lower for TV 2 than for TV 1 because of dilution from the added groundwater flow of the D and E aquifers.

Table M(a)-2 Contaminant Levels and Treatment Objective		
Contaminant	Groundwater Concentration (μg/l)	Treatment Objective (μg/l)
Target Volume 1		
TCE	215.0	≤0.5
PCE	108.0	≤0.5
1,1-DCE	29.6	≤0.5
cis-1,2-DCE	247.9	≤0.5
Vinyl Chloride	49.6	≤0.5
Benzene	0.6	≤0.5
Target Volume 2		
TCE	106.3	≤0.5
PCE	50.2	≤0.5
1,1-DCE	13.7	≤0.5
cis-1,2-DCE	115.0	≤0.5
Vinyl Chloride	23.0	≤0.5

Treatment Option Descriptions

Three treatment options will be considered: (1) air stripping, (2) liquid-phase activated carbon, and (3) advanced UV oxidation. Figure M(a)-1 illustrates each treatment option. The following sections describe each option.

Option A–Air Stripping

This technology uses air-water contacting towers to promote transfer of contaminants from the water into an airstream. This airstream is directed into an offgas treatment system, which is discussed in Appendix L, Vadose Zone Treatment Options. The system includes fiberglass-reinforced plastic (FRP) stripping towers, centrifugal fans to force air through the system, duct heaters to lower the relative humidity of the effluent airstream to the offgas treatment system, acid wash systems to periodically clean the packing of precipitated solids, and FRP ducting to convey and disperse the air.

Water treatment using air stripping will be effective in removing all the listed contaminants to a certain degree depending on the contaminants volatility. The design and treatment capability of an air stripper is dependent on the least volatile contaminant concentration and the treatment objective. TV 1 can be treated using a single tower

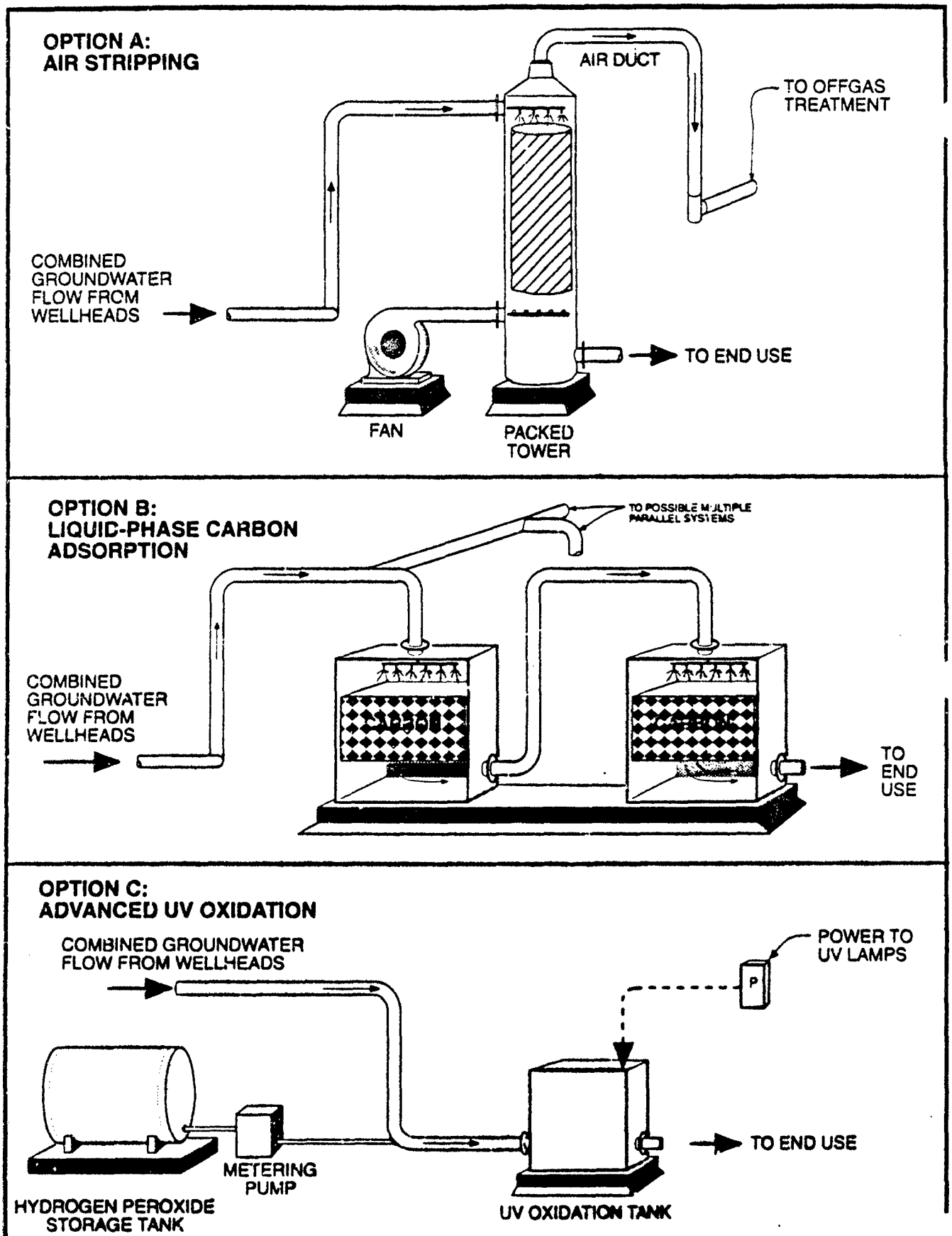

FIGURE M(a)-1
WATER TREATMENT OPTIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

RDD1412_250
5056.19

of approximately 7.5 feet in diameter, and 25 feet in height is required to reach the treatment objective. TV 2 can also be treated using a single tower of the same diameter, but the height of the tower is approximately 30 feet.

Option B—Liquid-Phase Carbon Adsorption

This technology uses direct contact of the contaminated water with activated-carbon to promote adsorption of contaminants onto the carbon and removal from the waterstream. The systems are skid-mounted modular units, consisting of two carbon vessels on each skid. Each skid is capable of treating up to approximately 700 gpm. Skids come complete with pressure-rated vessels designed for up to 75 psig.

Carbon treatment of contaminated water will typically remove most of the contaminants present to <0.5 μg/l using the vessels in parallel and series. Periodic carbon regeneration is required and is accomplished by removing the carbon from the vessel, hauling it to a regeneration facility, and heating it in a furnace to a temperature which evaporates and incinerates the adsorbed contaminants. The regenerated carbon is then reused.

For TV 1, one skid is necessary to accommodate the flow from the B and C aquifer. For TV 2, two skids are required for the higher flow.

Option C—Advanced UV Oxidation

This technology uses a chemical reagent and UV light to oxidize the contaminants identified at the Davis Site into nonhazardous species. The reagent used is aqueous solutions of hydrogen peroxide. The advanced UV oxidation system components include a hydrogen peroxide storage tank and metering pump and a reaction chamber with multiple contact cells which mix the wastewater with small amounts of hydrogen peroxide in the presence of UV light. The system requires power for UV lamps and periodic offloading of hydrogen peroxide to the storage facility.

Treatment to nondetect levels can be accomplished with these units through the residence time and peroxide dose. For TV 1, it is assumed one UV/peroxide oxidation modular system is required to achieve the treatment objective. For TV 2, one larger UV/peroxide oxidation modular system is required. Case studies involving UV oxidation are included in Attachment M(a)-4.

Option Evaluation Criteria

The options were evaluated on the basis of four important criteria relevant to justify implementation of the options. The criteria are listed and described as follows:

Status of Development

The option's track record is usually reflected by the degree to which the remediation method is considered proven commercial technology. Innovative technologies obviously would not have a track record and hence predicting their reliability and performance is difficult.

Efficiency

The destruction removal efficiency (DRE) is the single most important characteristic of the remediation option. It is typically expressed as a percentage and is computed as follows:

$$\frac{[\textit{Mass of component} - \textit{Mass of component}]}{\textit{Mass of component in feed stream}} * 100$$

Reliability

Reliability refers to the option's consistency and safety during operation. For instance, an option that needs frequent shutdowns cannot be considered reliable.

Costs

The costs refer to the capital and operation and maintenance (O&M) cost estimates associated with each option. These cost estimates have been assembled for inclusion into the alternative cost estimates. The cost estimates developed are order-of-magnitude estimates. These estimates are expected to be accurate within +30 to -30 percent and provide a basis for comparison between treatment alternatives. The detailed breakdowns of capital and O&M costs for each option are given in the attachments to this technical memorandum. The detailed breakdowns for air stripping are presented in Attachment M(a)-1, for liquid-phase carbon adsorption in Attachment M(a)-2, and for UV oxidation in Attachment M(a)-3.

Capital Costs

Capital costs include those costs associated with the original equipment, including the cost of the process control, and auxiliary units. It also includes the installation, contractor profit, and a small contingency. The percentages used in the treatment facility costs are consistent for a given technology, but may vary from one alternative to another. The percentages used in these estimates were determined using *Plant Design and Economics for Chemical Engineers* (Peters and Timmerhaus, 1990), *Chemical Engineering Economics* (Garrett, 1989), and past professional experience. These costs do not include other contingencies for scope changes, permitting and legal fees, or design fees. These other contingencies and fees are assumed to be more accurately

applied to each alternative cost estimate. Table M(a)-3 summarizes the capital costs for TV 1 for each option. Table M(a)-4 summarizes the capital cost for TV 2.

Table M(a)-3
Capital Costs
Davis Site Treatment Facility
(TV 1)

Description	Cost ($)		
	Air Stripping	Liquid-Phase Carbon Adsorption	UV Oxidation
Treatment Facility Costs	501,000	347,000	296,000
Site Preparation	14,000	14,000	14,000
Land	0	0	0
Total Construction Costs	515,000	361,000	310,000

Table M(a)-4
Capital Costs
Davis Site Treatment Facility
(TV 2)

Description	Cost ($)		
	Air Stripping	Liquid-Phase Carbon Adsorption	UV Oxidation
Treatment Facility Costs	551,000	693,000	492,000
Site Preparation	14,000	14,000	14,000
Land	0	0	0
Total Construction Costs	565,000	707,000	506,000

The capital costs for air stripping and liquid-phase carbon adsorption were estimated using cost estimating software systems Stripper and CORA. The Stripper software system is a design model for air stripping. Stripper takes the detailed conditions and treatment objectives of the specified site and calculates the design parameters for an air stripping column. The CORA software system is a cost estimating system that takes the site conditions and selected treatments and calculates the capital and O&M costs for each treatment along with site preparation costs. Estimating capital cost for the air stripping option was calculated using the design parameters from Stripper. Quotes from vendors were used to estimate the capital cost for the liquid-phase carbon adsorption and the UV oxidation options. The air stripping capital cost was compared to vendor quotes obtained for similar treatment systems.

Operation and Maintenance Costs

The O&M costs reflect the maintenance and reliability of a system. Operating costs are annual recurring costs and include the costs associated with day-to-day operation and routine maintenance. The O&M costs include the following:

- *Labor* - cost associated with manual operation and maintenance of the option. This cost may vary depending on the number of units for each option.

- *Materials* - cost associated with maintenance costs, administrative costs, disposal of personal protective equipment (PPE) or replacement materials, and items needed for the option process, such as sodium hypochlorite for washing the air stripping tower, carbon for the liquid-phase carbon adsorption, or hydrogen peroxide for the UV oxidation process.

- *Analytical* - cost associated with weekly sampling of the influent and effluent streams of each option. This cost may vary depending on the number of units for each option and the number of influent and effluent streams into each unit.

- *Health and Safety* - cost associated with refresher training, annual physical examinations, health and safety monitoring equipment, and PPE.

- *Power* - cost associated with power to run the units and their auxiliary equipment.

- *Contingency* - cost associated with nonroutine maintenance or operation.

Table M(a)-5 summarizes the O&M costs for TV 1 for each option. Table M(a)-6 summarizes the O&M cost for TV 2.

O&M costs for air stripping and liquid-phase carbon adsorption were estimated using vendor information and calculation methods outlined in ***Hazardous Waste Remediation Operations and Maintenance Cost Estimating Guidance Manual*** prepared in September 1989 by CH2M HILL for the California Department of Health Services. For UV oxidation, the guidance manual was used for general O&M costs such as labor, analytical, and health and safety. However, the materials, parts, and power for UV oxidation were directly acquired from the vendors.

Table M(a)-5 O&M Costs Davis Site Treatment Facility (TV 1)			
	Cost ($)		
Description	Air Stripping	Liquid-Phase Carbon Adsorption	UV Oxidation
Labor	48,000	48,000	48,000
Materials	28,000	125,000	52,000
Analytical	125,000	125,000	125,000
Health and Safety	9,000	9,000	9,000
Power	3,000	0	5,000
Subtotal	213,000	307,000	239,000
Contingency-20 percent	43,000	61,000	48,000
Total Annual O&M Costs	256,000	368,000	287,000

Table M(a)-6 O&M Costs Davis Site Treatment Facility (TV 2)			
	Cost ($)		
Description	Air Stripping	Liquid-Phase Carbon Adsorption	UV Oxidation
Labor	48,000	48,000	48,000
Materials	31,000	178,000	110,000
Analytical	125,000	250,000	125,000
Health and Safety	9,000	9,000	9,000
Power	5,000	0	70,000
Subtotal	218,000	485,000	362,000
Contingency-20 percent	44,000	97,000	72,000
Total Annual O&M Costs	262,000	582,000	434,000

The total capital and O&M costs have been summarized in Table M(a)-7 for each option. To compare these options, a 30-year project life with an interest rate of 5 percent has been used in calculating a present worth cost of the facilities.

Table M(a)-7 Treatment Option Costs Summary			
Option	Capital Costs ($ x 1,000)	O&M Costs ($ x 1,000)	Present Worth (Assumed 30-year Project Life, 5% Interest Rate) ($ x 1,000)
Air Stripping *Target Volume 1*	515	256	4,450
Air Stripping *Target Volume 2*	565	262	4,592
Liquid-Phase Carbon Adsorption *Target Volume 1*	361	368	6,017
Liquid-Phase Carbon Adsorption *Target Volume 2*	707	582	9,652
Advanced UV Oxidation *Target Volume 1*	310	287	4,721
Advanced UV Oxidation *Target Volume 2*	506	434	7,176

Conclusions

Air stripping has been proven and used industrially for several years. As previously mentioned, the air stripping tower(s) is designed based on the contaminant concentration and the amount necessary to remove for remediation. Therefore, the towers are designed to be efficient and will have DREs for each contaminant of 99 percent or better. Air strippers are very reliable, but various elements can affect its performance. Bacterial growth, solids greater than 1 g/l, pH greater than 8, and dissolved iron greater than 1 ppm will all cause plugging or fouling of the tower. A pH less than 5 can cause corrosion. As indicated in Table M(a)-7, the 30-year present worth cost estimate for air stripping for remediation of TV 1 or TV 2 appears to be the most cost-effective in comparison to the other remediation options; however, offgas treatment from the tower(s) needs to be included in the remediation consideration of complete treatment of the groundwater. As discussed previously, the offgas treatment is discussed and evaluated in Appendix L.

Liquid-phase carbon adsorption has also been proven and used industrially for several years. As stated previously, carbon treatment of contaminated water will typically remove most of the contaminants present to <0.5 µg/l. Therefore, the contaminants will have DREs of 99 percent or better. However, vinyl chloride is hard to adsorb to carbon and its DRE will be within 30 to 50 percent. The carbon vessels are highly

reliable and do not require any special maintenance except for carbon replacement. In the 30-year present worth cost estimate, liquid-phase carbon adsorption is very costly for the remediation of both TV 1 and TV 2.

Advanced UV oxidation is a proven remediation technology, but has not been in industrial use for as long as either air stripping or liquid-phase carbon adsorption. As discussed previously, UV oxidation treatment to nondetect levels can be accomplished through the residence time and peroxide dose. Therefore, UV oxidation is efficient and the DRE for each contaminant is 99 percent or better. The UV oxidation units are highly reliable and need little maintenance except for UV lamp replacement and replenishing the hydrogen peroxide supply. As seen with the 30-year present worth cost estimate, UV oxidation is also a low cost for either TV 1 or TV 2.

All the options are analogous in regards to status of development, reliability, and efficiency. Therefore, cost is the deciding factor for the choice of options. Liquid-phase carbon adsorption cannot efficiently remove the vinyl chloride which is present in the influent water to the treatment system and is expensive compared to the other options. Therefore, carbon treatment cannot be considered as the option choice. Considering that off treatment must be regarded with air stripping for complete treatment of the groundwater, the air stripping option costs will increase and undoubtedly exceed the cost of the UV oxidation option. Therefore, it is concluded that UV oxidation is the preferred remediation option. There are many future technological advancements for UV oxidation that may be used to enhance the remediation process. These future advancements are discussed in detail in the main text of this report.

Works Cited

CH2M HILL. 1989. *Hazardous Waste Remediation Operations and Maintenance Cost Estimating Guidance Manual.* Prepared for the California Department of Health Service.

Garrett, Donald E. 1989. *Chemical Engineering Economics.*

Peters and Timmerhaus. 1990. *Plant Design and Economics for Chemical Engineers.*

Attachment M(a)-1

AIR STRIPPING
DAVIS TREATMENT FACILITY COSTS
Target Volume 1

Hours per day of operation=	24
Weeks per year of operation=	52
Number of employees=	2
Influent samples per year=	52
Effluent samples per year=	52

Capitol Costs: **Comments:**

Treatment Facility Costs:			
Purchased Equipment		$194,867	Scaled Vendor Quote
Equipment Installation	47%	$91,588	Reference 1*
Instrumentation	18%	$35,076	Reference 1
Piping & Ducts (installed)	66%	$128,613	Reference 1
Electrical (installed)	11%	$21,435	Reference 1
Contractor's Fee	5%	$9,743	Reference 1
Contingency	10%	$19,487	Reference 1
		$500,809	
Site Preparation:			
Costs		$13,700	From CORA
		$13,700	
Land:			
2 acres needed		$0	Land already owned
		$0	
Total Construction Cost:		**$514,509**	

Annual Operations and Maintenance Costs:**

Labor:		
A. Operational Labor		
Air Stripping	832 hr/yr	$29,120
B. Additional Labor	166.4 hr/yr	$7,488
C. Supervisor Labor	200 hr/yr	$10,982
		$47,590
Materials:		
A. Sodium Hypochlorite		$969
B. Annual Maintenance Cost		$25,725
C. Administrative Costs		$1,286
D. Disposal		
PPE		$112
		$28,093
Analytical:		
A. Samples		
Air Stripping		$124,800 Sampled weekly

		$124,800	
Health and Safety:			
A. Training			Initial training costs included in
Refresher		$2,500	the capital cost estimate
B. Physical Exams		$576	
C. Health & Safety Monitoring Equipment		$2,246	
D. PPE		$3,744	Modified Level D
		$9,066	
Power:			
A. Air Stripping			
Fan		$3,342	Pump cost included in Wellhead
		$3,342	costs.
Contingency:	20%	$42,579	
Total Annual C & M Cost:		$255,471	

Note: *Reference 1: "Plant Design and Economics for Chemical Engineers" by Peters and Timmerhaus and "Chemical Engineering Economics" by Garrett.

**O&M Costs Estimated Based on "Hazardous Waste Remediation Operations & Maintenance Cost Estimating Guidance Manual."

AIR STRIPPING
DAVIS TREATMENT FACILITY COSTS
Target Volume 1
Summary Table

Capitol Costs:

Treatment Facility Costs:		$501,000
Site Preparation:		$14,000
Land:		$0
Total Construction Cost:		$515,000

Annual Operations and Maintenance Costs:

Labor:		$48,000
Materials:		$28,000
Analytical:		$125,000
Health and Safety:		$9,000
Power:		$3,000
Contingency:	20%	$43,000
Total Annual O & M Cost:		$256,000

AIR STRIPPING
DAVIS TREATMENT FACILITY COSTS
Target Volume 2

Hours per day of operation=	24
Weeks per year of operation=	52
Number of employees=	2
Influent samples per year=	52
Effluent samples per year=	52

Capitol Costs: **Comments:**

Treatment Facility Costs:			
Purchased Equipment		$214,402	Scaled Vendor Quote
Equipment Installation	47%	$100,769	Reference 1*
Instrumentation	18%	$38,592	Reference 1
Piping & Ducts (installed)	66%	$141,505	Reference 1
Electrical (installed)	11%	$23,584	Reference 1
Contractor's Fee	5%	$10,720	Reference 1
Contingency	10%	$21,440	Reference 1
		$551,014	
Site Preparation:			
Costs		$13,700	From CORA
		$13,700	
Land:			
2 acres needed		$0	Land already owned
		$0	
Total Construction Cost:		$564,714	

Annual Operations and Maintenance Costs:**

Labor:		
A. Operational Labor		
Air Stripping	832 hr/yr	$29,120
B. Additional Labor	166.4 hr/yr	$7,488
C. Supervisor Labor	200 hr/yr	$10,982
		$47,590
Materials:		
A. Sodium Hypochlorite		$969
B. Annual Maintenance Cost		$28,236
C. Administrative Costs		$1,412
D. Disposal		
PPE		$112
		$30,729
Analytical:		
A. Samples		
Air Stripping		$124,800 Sampled weekly

		$124,800	
Health and Safety:			
A. Training			Initial training costs included in
Refresher		$2,500	the capital cost estimate
B. Physical Exams		$576	
C. Health & Safety Monitoring Equipment		$2,246	
D. PPE		$3,744	Modified Level D
		$9,066	
Power:			
A. Air Stripping Fan		$5,351	Pump cost included in Wellhead costs.
		$5,351	
Contingency:	20%	$43,507	
Total Annual O & M Cost:		$261,044	

Note: *Reference 1: "Plant Design and Economics for Chemical Engineers" by Peters and Timmerhaus and "Chemical Engineering Economics" by Garrett.

**O&M Costs Estimated Based on "Hazardous Waste Remediation Operations & Maintenance Cost Estimating Guidance Manual."

AIR STRIPPING
DAVIS TREATMENT FACILITY COSTS
Target Volume 2
Summary Table

Capitol Costs:

Treatment Facility Costs:		$551,000
Site Preparation:		$14,000
Land:		$0
Total Construction Cost:		$565,000

Annual Operations and Maintenance Costs:

Labor:		$48,000
Materials:		$31,000
Analytical:		$125,000
Health and Safety:		$9,000
Power:		$5,000
Contingency:	20%	$44,000
Total Annual O & M Cost:		$262,000

Attachment M(a)-2

LIQUID PHASE ACTIVATED CARBON
DAVIS TREATMENT FACILITY COSTS
Target Volume 1

Number of Units=	1	
Hours per day of operation=	24	
Weeks per year of operation=	52	
Number of employees=	2	
Groundwater Flows=	380	gpm
Influent samples per year=	52	
Effluent samples per year=	52	

Capitol Costs: **Comments:**

Treatment Facility Costs:			
Purchased Equipment		$175,000	Vendor Quote
Equipment Installation	27%	$47,250	Reference 1*
Instrumentation	10%	$17,500	Reference 1
Piping & Ducts (installed)	35%	$61,250	Reference 1
Electrical (installed)	11%	$19,250	Reference 1
Contractor's Fee	5%	$8,750	Reference 1
Contingency	10%	$17,500	Reference 1
		$346,500	
Site Preparation:			
Costs		$13,700	From CCRA
		$13,700	
Land:			
2 acres needed		$0	Land already owned
		$0	
Total Construction Cost:		$360,200	

Annual Operations and Maintenance Costs:**

Labor:			
A Operational Labor	832 hy/yr	$29,120	
B. Additional Labor	166 hr/yr	$7,488	
C. Supervisor Labor	200 hr/yr	$10,982	
		$47,590	
Materials:			
A. Carbon Replacement		$105,967	$1/lb of carbon
B. Annual Maintenance Cost		$18,010	
C. Administrative Costs		$901	
D. Disposal			
PPE		$112	
		$124,990	
Analytical:			
A. Samples		$124,800	

		$124,800	
Health and Safety:			
A. Training			Initial training included in
Refresher		$2,500	the capital cost estimate
B. Physical Exams		$576	
C. Health & Safety Monitoring Equipment		$2,246	
D. PPE		$3,744	Modified Level D
		$9,066	
Power:			
No power		$0	Pump cost included in Wellhead
		$0	costs.
Contingency:	20%	$61,289	
Total Annual O & M Cost:		$367,736	

Note: *Reference 1: "Plant Design and Economics for Chemical Engineers" by Peters and Timmerhaus and "Chemical Engineering Economics" by Garrett.

**O&M Costs Estimated Based on "Hazardous Waste Remediation Operations & Maintenance Cost Estimating Guidance Manual."

LIQUID PHASE ACTIVATED CARBON
DAVIS TREATMENT FACILITY COSTS
Target Volume 1
Summary Table

Capitol Costs:

Treatment Facility Costs:		$347,000
Site Preparation:		$14,000
Land:		$0
Total Construction Cost:		$361,000

Annual Operations and Maintenance Costs:

Labor:		$48,000
Materials:		$125,000
Analytical:		$125,000
Health and Safety:		$9,000
Power:		$0
Contingency:	20%	$61,000
Total Annual O & M Cost:		$368,000

LIQUID PHASE ACTIVATED CARBON
DAVIS TREATMENT FACILITY COSTS
Target Volume 2

Number of Units=	2	
Hours per day of operation=	24	
Weeks per year of operation=	52	
Number of employees=	2	
Groundwater Flows=	820	gpm
Influent samples per year=	104	
Effluent samples per year=	104	

Capitol Costs: **Comments:**

Treatment Facility Costs:			
Purchased Equipment		$350,000	Vendor Quote
Equipment Installation	27%	$94,500	Reference 1*
Instrumentation	10%	$35,000	Reference 1
Piping & Ducts (installed)	35%	$122,500	Reference 1
Electrical (installed)	11%	$38,500	Reference 1
Contractor's Fee	5%	$17,500	Reference 1
Contingency	10%	$35,000	Reference 1
		$693,000	
Site Preparation:			
Costs		$13,700	From CORA
		$13,700	
Land:			
2 acres needed		$0	Land already owned
		$0	
Total Construction Cost:		$706,700	

Annual Operations and Maintenance Costs:**

Labor:			
A. Operational Labor	832 hy/yr	$29,120	
B. Additional Labor	168 hr/yr	$7,488	
C. Supervisor Labor	200 hr/yr	$10,982	
		$47,590	
Materials:			
A. Carbon Replacement		$140,756	$1/lb of carbon
B. Annual Maintenance Cost		$35,335	
C. Administrative Costs		$1,767	
D. Disposal			
PPE		$112	
		$177,970	
Analytical:			
A. Samples		$249,600	

		$249,600	
Health and Safety:			
A. Training			Initial training included in
Refresher		$2,500	the capital cost estimate
B. Physical Exams		$576	
C. Health & Safety Monitoring Equipment		$2,246	
D. PPE		$3,744	Modified Level D
		$9,066	
Power:			
No power		$0	Pump cost included in Wellhead
		$0	costs.
Contingency:	20%	$96,845	
Total Annual O & M Cost:		$581,072	

Note: *Reference 1: "Plant Design and Economics for Chemical Engineers" by Peters and Timmerhaus and "Chemical Engineering Economics" by Garrett.

**O&M Costs Estimated Based on "Hazardous Waste Remediation Operations & Maintenance Cost Estimating Guidance Manual."

LIQUID PHASE ACTIVATED CARBON
DAVIS TREATMENT FACILITY COSTS
Target Volume 2
Summary Table

Capitol Costs:

Treatment Facility Costs:		$693,000
Site Preparation:		$14,000
Land:		$0
Total Construction Cost:		$707,000

Annual Operations and Maintenance Costs:

Labor:		$48,000
Materials:		$178,000
Analytical:		$250,000
Health and Safety:		$9,000
Power:		$0
Contingency:	20%	$97,000
Total Annual O & M Cost:		$582,000

Attachment M(a)-3

UV/OXIDATION
DAVIS TREATMENT FACILITY COSTS
Target Volume 1

Number of Units=	1	
Hours per day of operation=	24	
Weeks per year of operation=	52	
Number of employees=	2	
Groundwater Flows=	380	gpm
Influent samples per year=	52	
Effluent samples per year=	52	

Capitol Costs: **Comments:**

Treatment Facility Costs:			
Purchased Equipment		$150,000	Vendor Quote
Equipment Installation		$7,500	Vendor Quote
Instrumentation	22%	$33,000	Reference 1*
Piping & Ducts (installed)	40%	$60,000	Reference 1
Electrical (installed)	15%	$22,500	Reference 1
Contractor's Fee	5%	$7,500	Reference 1
Contingency	10%	$15,000	Reference 1
		$295,500	
Site Preparation:			
Costs		$13,700	From CORA
		$13,700	
Land:			
2 acres needed		$0	Land already owned
		$0	
Total Construction Cost:		$309,200	

Annual Operations and Maintenance Costs:**

Labor:			
A. Operational Labor	832 hr/yr	$29,120	
B. Additional Labor	166.4 hr/yr	$7,488	
C. Supervisor Labor	200 hr/yr	$10,982	
		$18,470	
Vendor Material and Parts O&M:		$52,000	H2O2 @ $.65/lb 50%
Analytical:			
A. Samples		$124,800	
		$124,800	
Health and Safety:			
A. Training			
Refresher		$2,500	

B. Physical Exams		$576	
C. Health & Safety Monitoring Equipment		$2,246	
D. PPE		$3,744	Modified Level D
		$9,066	
Vendor Power O&M:		$5,000	60 kW @ $.06/kWh
Contingency:	20%	$41,867	
Total Annual O & M Cost:		$251,204	

Note: "Reference 1: "Plant Design and Economics for Chemical Engineers" by Peters and Timmerhaus and "Chemical Engineering Economics" by Garrett.

**O&M Costs Estimated Based on "Hazardous Waste Remediation Operations & Maintenance Cost Estimating Guidance Manual."

UV/OXIDATION
DAVIS TREATMENT FACILITY COSTS
Target Volume 1
Summary Table

Capitol Costs:

Treatment Facility Costs:		$296,000
Site Preparation:		$14,000
Land:		$0
Total Construction Cost:		$310,000

Annual Operations and Maintenance Costs:

Labor:		$18,000
Vendor Material and Parts O&M:		$52,000
Analytical:		$125,000
Health and Safety:		$9,000
Vendor Power O&M:		$5,000
Contingency:	20%	$42,000
Total Annual O & M Cost:		$251,000

UV/OXIDATION
DAVIS TREATMENT FACILITY COSTS
Target Volume 2

Number of Units=	1	
Hours per day of operation=	24	
Weeks per year of operation=	52	
Number of employees=	2	
Groundwater Flows=	820	gpm
Influent samples per year=	52	
Effluent samples per year=	52	

Capitol Costs: **Comments:**

Treatment Facility Costs:			
Purchased Equipment		$250,000	Vendor Quote
Equipment Installation		$12,000	Vendor Quote
Instrumentation	22%	$55,000	Reference 1*
Piping & Ducts (installed)	40%	$100,000	Reference 1
Electrical (installed)	15%	$37,500	Reference 1
Contractor's Fee	5%	$12,500	Reference 1
Contingency	10%	$25,000	Reference 1
		$492,000	
Site Preparation:			
Costs		$13,700	From CORA
		$13,700	
Land:			
2 acres needed		$0	Land already owned
		$0	
Total Construction Cost:		$505,700	

Annual Operations and Maintenance Costs:**

Labor:			
A. Operational Labor	832 hr/yr	$29,120	
B. Additional Labor	166.4 hr/yr	$7,488	
C. Supervisor Labor	200 hr/yr	$10,982	
		$18,470	
Vendor Material and Parts O&M:		$110,000	H2O2 @ $.65/lb 50%
Analytical:			
A. Samples		$124,800	
		$124,800	
Health and Safety:			
A. Training			
Refresher		$2,500	

B. Physical Exams		$576	
C. Health & Safety Monitoring Equipment		$2,246	
D. PPE		$3,744	Modified Level D
		$9,066	
Vendor Power O&M:		$70,000	135 kW @ $.06/kWh
Contingency:	20%	$66,467	
Total Annual O & M Cost:		$398,804	

Note: *Reference 1: "Plant Design and Economics for Chemical Engineers" by Peters and Timmerhaus and "Chemical Engineering Economics" by Garrett.
**O&M Costs Estimated Based on "Hazardous Waste Remediation Operations & Maintenance Cost Estimating Guidance Manual."

UV/OXIDATION
DAVIS TREATMENT FACILITY COSTS
Target Volume 2
Summary Table

Capitol Costs:

Treatment Facility Costs:		$492,000
Site Preparation:		$14,000
Land:		$0
Total Construction Cost:		$506,000

Annual Operations and Maintenance Costs:

Labor:		$18,000
Vendor Material and Parts O&M:		$110,000
Analytical:		$125,000
Health and Safety:		$9,000
Vendor Power O&M:		$70,000
Contingency:	20%	$66,000
Total Annual O & M Cost:		$398,000

Attachment M(a)-4

CHEMICAL OXIDATION OF DISSOLVED HAZARDOUS ORGANIC MATERIALS

by

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Presented at

Hazwaste '90 Symposium
Phoenix, Arizona

November 29, 1990

Chemical Oxidation of Dissolved Hazardous Organic Materials

by

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ABSTRACT

Most conventional water treatment technologies are based on converting the state or phase of the contamination. Removal of hazardous organic contamination from water by solid-phase adsorption and removal of volatile organics from water by air stripping are two such examples. In these approaches, subsequent treatment is required to complete the removal of the contaminant from the environment. True destruction of the organic contaminants has been left to incineration for high concentration wastes or biological oxidation for low level non-toxic materials.

More recently, advances in mechanical and electrical design, as well as more stringent treatment requirements, have made chemical oxidation a viable treatment alternative. One of the most promising of these innovative processes involves ultraviolet light catalyzed chemical oxidation of organics in water using hydrogen peroxide. Dissolved organics are converted to carbon dioxide and water. Where halogenated solvents are treated, the attendant halide remains dissolved. Operating field units have been in place for as long as 10 years.

Peroxidation Systems, Inc. of Tucson, Arizona, the leader in the chemical oxidation field, has over 35 full-scale installations including three systems in Arizona. Both laboratory and field performance data are presented to demonstrate the process effectiveness on a variety of hazardous organic contaminants. The process can be operated as a closed system generating no air emission, solid residuals, or other secondary pollution problems. Treated water is suitable for discharge, reinjection or reuse.

INTRODUCTION

Most early environmental pollution controls were based upon visual indicators. Smokestacks emitting particulates, fish kills due to gross toxicity, organic discharges leading to oxygen depletion in rivers, and algae blooms in lakes were the main focus. Tens of parts-per-million were the controversial effluent levels and fishable, swimmable waterways the goals.

More recently, the abilities of analytical laboratories to detect sub part-per-billion levels of contaminants and studies linking long-term, low-level exposure to health problems, have shifted regulatory concerns to many previously neglected areas.

The fairly recent discoveries of the magnitude and extent of the contamination of our groundwater resources has lead to a new emphasis on groundwater clean-up. The disposal of wastes on or under the ground met the early environmental goals of not discharging to air or surface waters. However, an even greater problem of groundwater contamination was created. Ever since Love Canal in the late 1970's and the formation of the Superfund program in 1980,

hazardous and toxic materials in the ground and groundwater have received a great deal of scrutiny while the definition of acceptable treatment levels has moved ever lower. In order to treat hazardous organic contaminants in water to low part per billion levels, many of the conventional technologies employed in the past become very expensive or are not feasible. One of the more innovative approaches to producing very high purity water is chemical oxidation. The most promising method is to use an oxidant such as hydrogen peroxide or ozone, which contain no extraneous products, and employ ultraviolet light to catalyze the oxidation reaction.[1] This process has been in use for a number of years, but recent advances in hardware technology have made chemical oxidation economically competitive with conventional treatment methods and, in many instances, it is the process of choice.[2]

THE UV/PEROXIDATION PROCESS

Chemical oxidation of organic contaminants in water is a technology which can be applied to a broad spectrum of aqueous wastes. The process, when carried to completion, converts hydrocarbon contaminants to carbon dioxide and water. Any halogens present in the organic molecule are converted to the corresponding inorganic halides.

When either hydrogen peroxide (H_2O_2) or ozone is catalyzed with ultraviolet (UV) light, hydroxyl radicals are formed which then react with the organic contaminant. The oxidation potentials for common oxidants are listed in Table 1. As shown, the hydroxyl radical is second only to fluorine in oxidative power.

Table 1

Oxidation Potential of Oxidants

Relative Oxidation Power Chlorine=1.0	Species	Oxidative Potential (Volts)
2.23	Fluorine	3.03
2.06	Hydroxyl Radical	2.80
1.78	Atomic Oxygen (singlet)	2.42
1.52	Ozone	2.07
1.31	Hydrogen Peroxide	1.78
1.25	Perhydroxyl Radical	1.70
1.24	Permanganate	1.68
1.17	Hypochlorous Acid	1.59
1.15	Chlorine Dioxide	1.57
1.10	Hypochlorous Acid	1.49
1.07	Hypoiodous Acid	1.45
1.00	Chlorine	1.36
0.80	Bromine	1.09
0.39	Iodine	0.54

The reaction of formic acid with UV catalyzed H_2O_2 illustrates the photochemical oxidation process.

$$H_2O_2 \xrightarrow[<400\ nm]{UV} 2 \cdot OH$$

$$HCOOH + \cdot OH \longrightarrow H_2O + HCOO\cdot$$

$$HCOO\cdot + \cdot OH \longrightarrow H_2O + CO_2$$

Neither H_2O_2 nor ozone contain metals or halogens which can lead to undesirable by-products during the organic oxidation process. However, H_2O_2 has certain inherent advantages and is preferred as the source of hydroxyl radicals over ozone. H_2O_2 is supplied commercially as an easily handled liquid (30-50%) which has infinite solubility in water. Ozone is a toxic gas with limited water solubility and must be generated on-site. Also, the solubility of H_2O_2 greatly simplifies the reactor design in terms of oxidant addition, mixing of the reactants, and elimination of concern over fugitive toxic gases which can contain ozone and the organic constituents.

Furthermore, H_2O_2 storage and feed systems are relatively inexpensive compared to ozone generation and feed equipment. Finally, hydroxyl radical formation from H_2O_2 is more efficient than from ozone, yielding two hydroxyl radicals from each molecule of H_2O_2.

Like most other treatment methods the UV/peroxidation process is dependent upon a number of conditions which can affect both performance and cost. Some process variables are inherent to the properties of the contaminated water while others can be controlled by the treatment system design and operation. Some of the more important process variables are summarized in Table 2.

Table 2

UV/Peroxidation Process Variables

Variables related to the contaminated water:

- type and concentration of organic contaminants
- light transmittance of the water (color/suspended solids)
- type and concentration of inorganic constituents

Variables related to treatment process design and operation

- UV and H_2O_2 dosages
- pH and temperature conditions
- use of catalysts

TREATMENT EQUIPMENT

While the UV/peroxidation process chemistry is well known, refined equipment design and the use of a high intensity UV source, such as that employed in the perox-pure™ system*, is a more recent development. The use of high intensity UV has produced a dramatic reduction

in contaminant oxidation time. Figure 1 presents data illustrating the relationship between UV intensity and required oxidation time for trichloroethene (TCE).

In full-scale treatment applications, implementation of the relationship shown in Figure 1 results in a perox-pure™ system utilizing 1 UV lamp in a 20 gallon reactor providing treatment equivalent to a system with 200 low intensity lamps in a 1500 gallon reactor. The increased operating cost for power with the perox-pure™ system is more than offset by the lower capital and maintenance costs of the equipment, and the smaller equipment size.

A flow diagram of a typical perox-pure™ system is shown in Figure 2. H_2O_2, which is stored on-site in polyethylene or aluminum tanks at 50% concentration, is injected into the influent water stream via chemical metering pumps. The solubility of H_2O_2 in water negates any need for mixing or dispersion devices other than the inlet piping. The water then flows into the oxidation chamber where it is brought into intimate contact with the UV lamps. The treated water exits the oxidation chamber, usually with a minor amount of residual H_2O_2, and is discharged as appropriate.

Individual perox-pure™ oxidation chambers may contain up to 15 UV lamps depending upon the water flow rate and the organic contaminant concentrations. As needed, the modular oxidation chambers are mounted in series or parallel to provide longer contact times or higher flow capacities. Such modular systems have been constructed with hydraulic capacities of up to 1500 gpm.

APPLICATION OF THE perox-pure™ PROCESS

The perox-pure™ Process is experiencing good success both in Arizona and other parts of the country and Europe. There are currently two units operating in Arizona, two additional units sold and three others in testing and under consideration.

Several case studies are presented below to illustrate the application of the perox-pure™ Process as a water treatment solution. The corresponding equipment design parameters and operating costs are discussed in each case.

Case A - Destruction of TCE in Groundwater

The groundwater plume beneath a residential area of a southern Arizona city was found to be contaminated with trichloroethene (TCE) and 1,2-dichloroethene (DCE). Peroxidation Systems, Inc. (PSI) was contracted to provide a treatment system for a 2-year remediation demonstration project to be conducted at a monitoring well located in the residential area. The monitoring well was selected based upon its production of the more contaminated water.

A perox-pure™ Model CW-180 was installed in December 1989, and was later replaced with a smaller unit, a Model LVB-90, based upon the favorable treatment results obtained and improved equipment design. The selection of the original treatment equipment was based upon a bench-scale study conducted at the PSI Testing Laboratory in Tucson, Arizona on a sample of the groundwater. The improved Model LVB-90 was able to achieve the same performance with one-third the power requirements.

* Peroxidation Systems, Inc., Tucson, Arizona

The current treatment process conditions and results for the Case A site are shown in Table 3. The groundwater is colorless with low solids content, a pH of 7.8, and low mg/l levels of inorganic constituents. The treatment flow rate is 135 gpm on a 24 hour per day, 7 day per week basis. A UV lamp power of 30 KW is utilized along with 15 mg/l of H_2O_2 to destroy 124 μg/l of TCE and 22 μg/l of DCE to less than 1 μg/l each. the treated groundwater is discharged to the sanitary sewer system at present.

Table 3

perox-pure™ Treatment Process
Conditions and Results for Case A

Flow Rate (gpm)	135
perox-pure™ Model	LVB-90
UV Lamp Power (KW)	30
H_2O_2 Dosage (mg/l)	15
Reaction Time (min.)	0.3
Influent Contaminants (μg/l)	
Trichloroethene	124
1,2-Dichloroethene	22
Effluent Contaminants (μg/l)	
Trichloroethene	< 1
1,2-Dichloroethene	< 1

The perox-pure™ system at the Case A site is being operated under a PSI Full Service Contract which eliminates capital expenditure and includes regular service, all parts and labor for maintenance, delivery of hydrogen peroxide and a guarantee of system performance. The operating cost for the system is approximately $0.83 per 1000 gallons treated including electrical power and the PSI Full Service Contract fee.

Case B - Destruction of BTEX in Groundwater

Groundwater monitoring near a lumber mill in Northern Arizona discovered high concentrations of BTEX (benzene, toluene, ethyl benzene and xylenes) and heavy hydrocarbons. The contamination was found to be a result of frequent gasoline spills from equipment at the mill previously operated at the site. PSI was contracted to provide a treatment system which would destroy the detectable organic contaminants to low μg/l level.

A perox-pure™ Model LVA-60 was installed at the Case B site in October 1989. Bench testing at the PSI Testing Laboratory was used to size the treatment equipment. The treatment is expected to continue for three to five years.

The operating conditions and treatment results for the Case B site are summarized in Table 4. The treatment flow rate is a constant 8.5 gpm, although the equipment is sized for approximately 25 gpm. The current flow rate is based upon the low output of the production wells at the site. A UV lamp power of 60 KW is used in conjunction with 200 mg/l of H_2O_2 to destroy 11,500 μg/l of BTEX and other hydrocarbons to below the analytical detection limits. The pH of the groundwater is reduced from 7.5 to approximately 6 with sulfuric acid prior to treatment to reduce the high alkalinity of the groundwater and prevent fouling of the perox-pure™ equipment. The treated water is used for dust control at the site.

Table 4

perox-pure™ Treatment Process
Conditions and Results for Case B

Flow Rate (gpm)	8.5
perox-pure™ Model	LVA-60
UV Lamp Power (KW)	60
H_2O_2 Dosage (mg/l)	200
Reaction Time (min.)	3.1
Influent Contaminants (μg/l)	
Benzene	2,540
Toluene	3,320
Ethylbenzene	353
Xylenes	2,490
Other Hydrocarbons	2,780
Effluent Contaminants (μg/l)	
Benzene	<1
Toluene	<1
Ethylbenzene	<1
Xylenes	<1
Other Hydrocarbons	<10

The perox-pure™ system at the Case B site is also being operated under a PSI Full Service Contract, providing all equipment, service, maintenance, chemical supply, and guaranteed performance. The operating cost for the treatment system, including electrical power and the Full Service Contract fee, is approximately $0.019 per gallon treated. This cost is relatively high due to the oversizing of the equipment. If the original design flow rate of 25 gpm is used, the projected treatment cost is $0.007 per gallon treated.

Case C - Combination Treatment

In May 1988 PSI was contracted by a consultant working for a Fortune 100 company with a contaminated groundwater site.

Preliminary estimates of the UV/Peroxidation process applicability were done using the extensive database accumulated by PSI from its treatment testing. Using rate constants from the database, the perox-pure™ Process was judged to be a viable alternative. A liquid phase granular activated carbon system, while considered technically feasible, was judged less desirable due to logistics of handling the spent carbon, cost and liabilities associated with spent carbon transport. The initial conceptual design was for the UV/Peroxidation Systems to act as a polish step after air stripping.

Because of the low flow estimated for treatment (25-50 gpm) and the bench-scale success, the smallest perox-pure™ production model, and LV-60, was chosen for the on-site demonstration. The unit was shipped to the site and the first testing of the system commenced in December.

Data from this initial testing is presented in Table 5. As can be seen from the data, the system was demonstrated to work at near 100% efficiency on most of the contaminants with destruction of 1,1,1-Trichloroethane (TCA) at 29%.

Table 5

Initial Test Data on UV/Peroxidation

Contaminant	INF* (µg/l)	EFF (µg/l)
1,1-DCA	4.5	<1.0
1,2-DCE	162	<1.0
1,1,1-TCA	105	74
TCE	68	<1.0
PCE	272	<1.0

Contact Time: 2.0 min.
H_2O_2: 40 mg/l

* Effluent from Air Stripper

While TCA has much less toxicity than the others and is usually allowed at up to 40 times the concentration of the others, the 74 ppb effluent was above the NPDES discharge limit. In order to make maximum use of both the air stripper and the UV/Peroxidation system the treatment system was replumbed to allow UV/Peroxidation first followed by the air stripper. Data from this treatment sequence is presented in Table 6. As is shown, the UV/Peroxidation destroyed virtually all contaminants with the exception of TCA which is subsequently reduced to below 2 µg/l by the air stripper. The result of this sequence is higher quality effluent water as well as much lower atmospheric emissions of chlorinated hydrocarbons obviating the need for vapor phase controls.

Table 6

UV/Peroxidation Performance Ahead of Air Stripper

Contaminant	Inf. (µg/l)	perox-pure™ Eff. (µg/l)	Air Stripper Eff. (µg/l)
MeCl	75	3.8	<2.0
1,2-DCE	3480	<2.0	<2.0
1,1,1-TCA	1980	1430	<2.0
TCE	1480	<2.0	<2.0
PCE	4990	<2.0	<2.0

The perox-pure™ system on this site is being operated on a Full Service Contract which eliminates capital expenditure and includes regular service, all parts and labor for maintenance, delivery of hydrogen peroxide and a guarantee of system performance. The cost to destroy the organics as shown with the perox-pure™ system is approximately $2.69 per 1000 gallons treated including capital amortization, chemicals, electricity and all maintenance parts and labor.

SUMMARY

hydrogen peroxide system (**perox-pure**™ Process), is a proven, effective technology for the removal of organic contamination from water. It is economically competitive with carbon adsorption and does away with the secondary disposal problems and liabilities which result from other technologies that produce sludges or air emissions. As air and water discharge regulations become more stringent, and disposal of spent adsorption materials becomes more costly, the **perox-pure**™ Process will come to be one of the technologies of choice for the 1990's.

REFERENCES

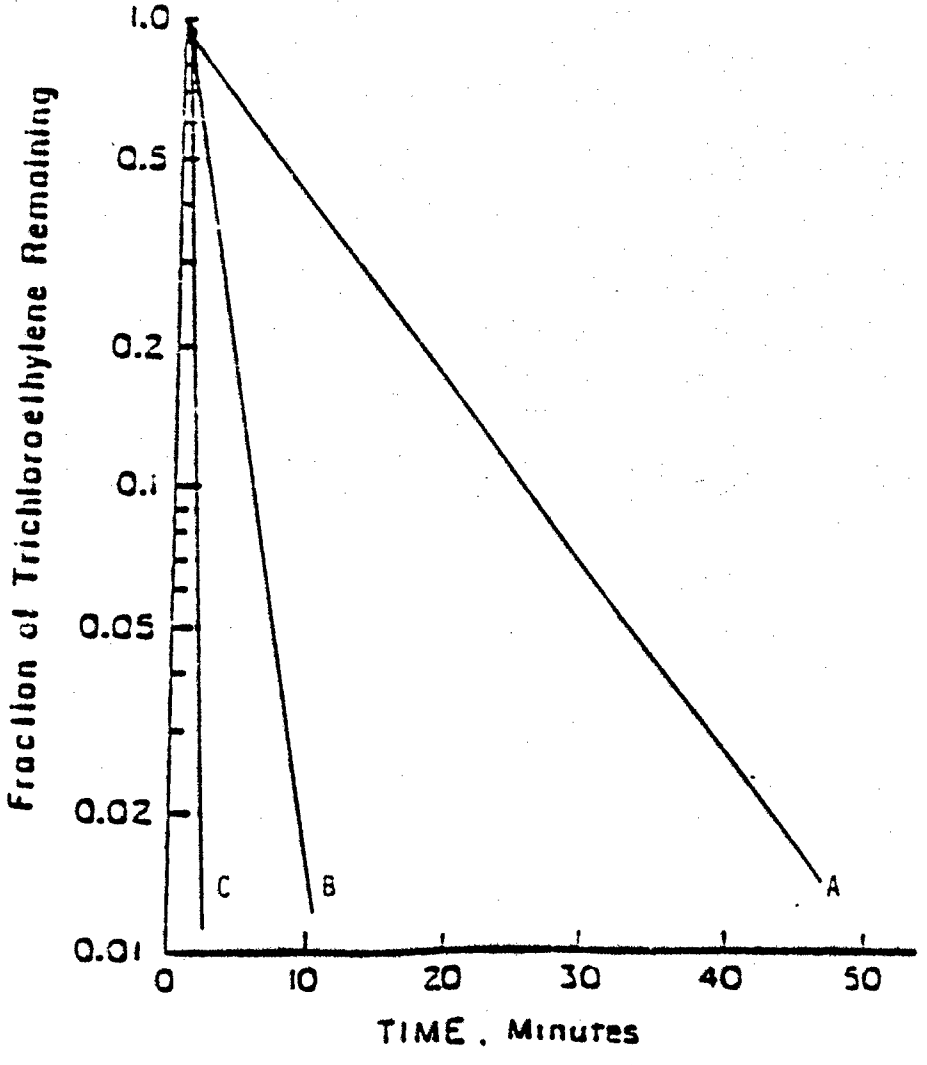
1. D.G. Hager and C.E. Smith, "The Destruction of Organic Contaminants in Water by Chemical Oxidation" in Proceedings of the Haztech International Conference and Exhibition; Institute for International Research, Denver, CO, 1986 pp. 215-231.

2. N.W. Gossett, J. Bausano and J. Oldham, "Start-up of an Innovative UV/Peroxidation Groundwater Treatment System," in Proceedings of the 10th National Superfund Conference and Exhibition, Hazardous Materials Control Research Institute, Washington, DC, 1989, pp. 306-308.

3. D.W. Sundstrom, H.E. Klei, T.A. Nalette, et al., "Destruction of Halogenated Aliphatics by Ultraviolet Catalyzed Oxidation with Hydrogen Peroxide" Hazardous Waste & Hazardous Materials, 3(1): 101 (1986).

FIGURE 1

EFFECT OF UV INTENSITY ON DESTRUCTION RATE

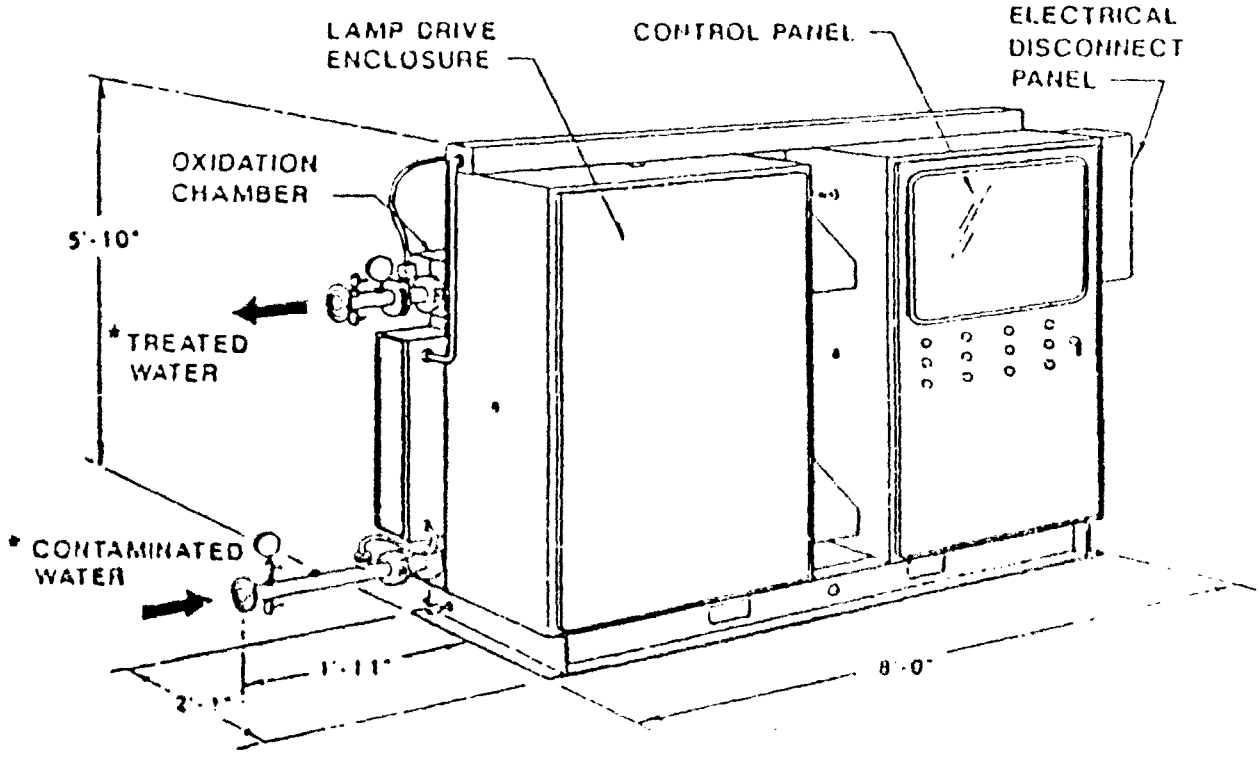


Line A - Data from Sundstrom[3] at 2.5 watts @ 254 nm/liter
Line B - Data from Hager[1] at 230 watts total UV/liter
Line C - Data from recent Peroxidation Systems testing at over 500 watts total UV/liter

FIGURE 2

TYPICAL EQUIPMENT CONFIGURATION

MODEL LV-60



RAYOX®

Second Generation Enhanced Oxidation Process for the Destruction of Waterborne Contaminants

APPLICATION OF RAYOX® FOR THE REMEDIATION OF CONTAMINATED GROUNDWATER

This paper contains excerpts from a presentation by
Dr. R.D.S. Stevens at the HazMat Central Conference, Chicago, Illinois, in March 1990

INTRODUCTION

Until recently, the remediation of groundwater contaminated with chlorinated organic compounds, (e.g. TCE, TCA, PCB, $CHCl_3$, PCP, etc.), or petroleum derived hydrocarbons (e.g. benzene, ethyl benzene, toluene, xylene or BETX) has, in large measure, been undertaken using either air stripping or activated carbon or a combination of both technologies.

Recent regulatory developments such as the San Francisco Bay Area Air Quality Regulations and the RCRA Land Bans have resulted in a greater interest in enhanced ("advanced") oxidation processes which carry no secondary pollution or disposal requirements.

This paper describes enhanced oxidation processes (EOP) generally and some of the features which account for the superior performance of second generation systems like Rayox®. It concludes with a discussion of results obtained in the remediation of a number of actual contaminated groundwaters.

The Enhanced ("Advanced") Oxidation Process

In the mid-seventies, a number of reports appeared describing the greatly enhanced rate of oxidation that was obtained when contaminated water with either dissolved O_3 or H_2O_2 was irradiated with ultraviolet (UV) light. One of the first reports was given by Prengle and co-workers *(1)*. The principles of this synergy are now understood and agreed upon in broad terms by researchers in this field. Recent discussions of the topic are given by Peyton *(2)*, Dore *(3)* and Hoigne et al *(4)*.

The results of these and other investigations have shown that the greatly increased rate of oxidation of waterborne contaminants obtained with an EOP was the result of the participation of powerful oxidizing radical agents such as the hydroxyl radical ($HO\bullet$) and the perhydroxyl radical ($HO_2\bullet$).

REACTION RATES OF OZONE AND HYDROXYL RADICALS WITH CLASSES OF ORGANIC COMPOUNDS (5)

COMPOUND	k, in L mole^{-1} s^{-1} O_3	OH
Olefins	1 to 450 x 10^3	10^9 to 10^{11}
S-containing organics	10 to 1.6 x 10^3	10^9 to 10^{10}
Phenols	10^3	10^9
N-containing organics	10 to 10^2	10^8 to 10^{10}
Aromatics	1 to 10^2	10^8 to 10^{10}
Acetylenes	50	10^8 to 10^9
Aldehydes	10	10^9
Ketones	1	10^9 to 10^{10}
Alcohols	10^{-2} to 1	10^8 to 10^9
Alkanes	10^{-2}	10^6 to 10^9
Carboxylic acids	10^{-3} to 10^{-2}	10^7 to 10^9

Table 1

SOLARCHEM ENVIRONMENTAL SYSTEMS

SOLARCHEM ENVIRONMENTAL SYSTEMS
130 Royal Crest Court
Markham, Ontario L3R 0A1
Tel: (416) 477-9242 • Fax: (416) 477-4511

SOLARCHEM ENVIRONMENTAL SYSTEMS
7320 Smoke Ranch Road, Suite H
Las Vegas, Nevada, U.S.A. 89128
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POSTULATED DESTRUCTION MECHANISM FOR CHLOROFORM (6)

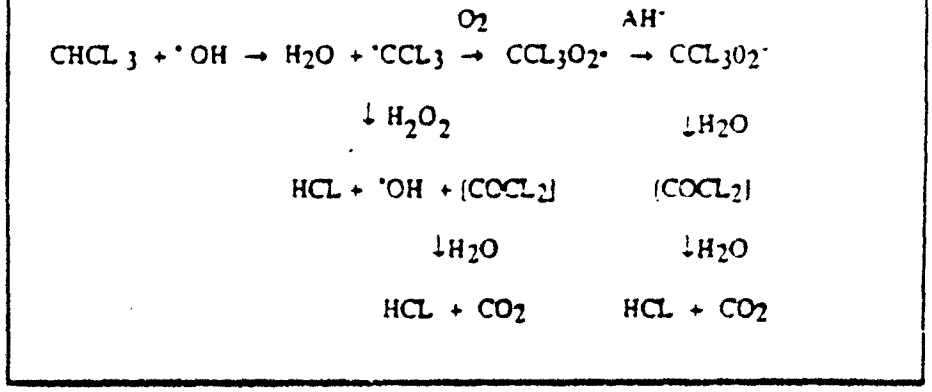

Figure 1

These radicals, once formed, aggressively attack a waterborne contaminant and initiate a typically rapid, oxidative cascade of reactions, which, in the case of a hydrocarbon or an oxygenated hydrocarbon, results ultimately in CO_2 and H_2O. If the contaminant is a chlorinated organic compound, the mineralization process will also result in the formation of chloride (Cl^-) ions.

An appreciation of the reason for the increased rate of decontamination obtainable by enhanced oxidation can be obtained by reviewing the data in Table 1, which lists the rate constant, k, for the reaction of O_3 and HO• with a number of different classes of organic compounds. These data show that the rate constant for HO• attack on organic compounds is typically a million (10^6) to a billion (10^9) times faster than molecular ozone.

Mechanism of Mineralization

There have been a number of investigations into the details of the chemistry involved in the enhanced oxidation process. The detailed, step by step chemical processes involved in the mineralization (i.e. conversion to CO_2, H_2O and Cl^-) of a contaminant depends upon of a number of factors such as the presence and concentration of other organic and inorganic species and the pH. Thus, the degradation pathway to CO_2, H_2O and Cl^- followed by a given contaminant can vary from stream to stream, depending upon the prevailing conditions in each stream. However, the mechanism typically involves several steps and intermediate species, even for relatively simple systems such those containing a single, low molecular weight contaminant. The reaction mechanism proposed in a recent paper by Getoff *(6)* for the mineralization of chloroform is presented in Figure (1).

From this representation one can see that even in the relatively simple situation where the contaminant molecule contains only one carbon, there are several steps involved in mineralization.

Intermediates or By Products

Since the mineralization process is multistep involving intermediates, the question of converting one contaminant into another (and potentially more undesirable) contaminant sometimes arises, particularly in first generation EOP systems.

Fortunately, this is not a problem with second generation EOP Systems . Although intermediates (including non radical ones) can and are produced, they are, under the conditions prevailing in an enhanced oxidation reactor, thermodynamically unstable with respect to CO_2 and H_2O. In other words the difference in free energy, ΔG, between any possible intermediate and CO_2, H_2O (and Cl-), is always negative.

Expressed in Equation form:

$$\text{Intermediate(s)} \xrightarrow{HO\bullet/O_2/H_2O} CO_2, H_2O, Cl^- \quad \Delta G \text{ is -ve}$$

This, of course, means that given adequate contact time, any and all intermediates will themselves be converted to CO_2, H_2O (and Cl^- if chlorine was present in the original contaminant). The question then arises as to what are the typical lifetimes of the intermediate species produced under the prevailing

conditions found in a second generation enhanced oxidation system like Rayox®..

Typically the lifetimes of many of the intermediates involved in an enhanced oxidation process would be very short, generally less than a millisecond (10^{-3}s). This is particularly true of the radical species, many of which would have a lifetime less than a microsecond (10^{-6}s)

The lifetime of any non-radical by-products or intermediates would be a function of the concentration of the various oxidizing species in solution (e.g. HO•, HO_2•, O_3 etc.) and the rate constant for the reaction between the oxidant and the compound in question. Mathematically this can be expressed as :

$$\tau_x = k_x^{-1} = (\Sigma k_i[R_i])^{-1}$$

where:
τ_x = lifetime of contaminant x

k_x= pseudo first order rate constant for the decay of x

k_i = rate constant for the reaction between X and radical oxidizing species Ri

[R] = concentration of the radical oxidizing species present (e.g. HO•)

For example, even if the by product was relatively refractory such as a carboxylic acid (e.g. formic acid) then

$$\tau = \left[10^8 \frac{L}{mole.s} \times 10^{-9} \frac{moles}{L}\right]^{-1} = 10s$$

where the following assumptions have been made:

- $k_i = 10^7 \frac{L}{mole \cdot s}$ (from Table 1)
- [HO•] = steady state concentration of the hydroxyl radical $= (10^{-9} \frac{moles}{L})$
- that the HO• radical is the only oxidant reacting with the carboxylic acid in question

In the above example, the concentration of the carboxylic acid would decrease by a factor of (1/e) (~0.37) every lifetime, or every 10 seconds. If the byproduct reacted more quickly (i.e. had a larger rate constant,k) with the oxidants in solution, or the concentration of the oxidizing species were higher, then the lifetime of the intermediate would be further reduced.

From the foregoing discussion, it can be seen that the concentration of any intermediates or by-products that might be formed as a result of the HO• attack on the original compound, can be reduced to whatever levels desired by simply ensuring that the contact or residence time is sufficiently long to achieve the target discharge criteria. What is usually observed in practice, however, given the highly reactive nature of the radical oxidizing species generated in the enhanced oxidation process, is that the contact times needed to reduce the concentration of the initial contaminants to target discharge values, also results in a satisfactorily complete destruction of any intermediates or by-products.

As a result of this near complete mineralization ("destruction") of any waterborne organic contaminants, the use of enhanced oxidation for groundwater remediation means that there is virtually never a secondary or downstream disposal or handling problem.

Rayox® - A Second Generation Enhanced Oxidation Process

Although enhanced oxidation has been found to be a highly effective method of remediating a broad range of contaminated groundwaters, earlier embodiments of the technology have had limited success in cost effectively destroying several of the more refractory waterborne contaminants such as CCl_4, $CHCl_3$, TCA, DCA, fixed cyanides, Freon, etc.

The reason for this relatively limited success is rooted in the fact that the rate constant for HO• attack of these compounds is relatively small. Examples of some more refractory compounds are given in Table 2.

REACTION RATE CONSTANTS OF HYDROXYL RADICALS WITH SELECTED REFRACTORY COMPOUNDS

Compound	k ($L \cdot mole^{-1}s^{-1}$)
CCl_4	1.5×10^6
$CHCl_3$	8.8×10^6
TCA	7×10^6
DCA	1.6×10^8
Freon 113	$\sim 6 \times 10^5$

Table 2

From Table 2 it can be seen that "k" for the reaction of HO• with TCA is $\sim 10^7$L mole^{-1}s^{-1} which is approximately 10^{-2} that for TCE. Thus, all other things being equal, it would take 100 times the contact time to achieve the same level of TCA destruction vs. that needed for TCE.

This likely explains, in large measure, why first generation enhanced oxidation systems have had limited success in achieving satisfactory rates of destruction of these more refractory compounds (7) i.e. these systems rely almost exclusively on radical (OH•) driven destruction. With Rayox®., however the contact times required to treat refractories like TCA are typically only 3-5 times that needed for TCE.

Destruction of Refractory Compounds with Rayox®.

To illustrate the powerful decontamination capability of Rayox®., some typical results for the destruction of several refractory contaminants are given below:

Figure (2) shows the results for the reduction of the chloroform from about 30 ppm to less than 0.1 ppm.

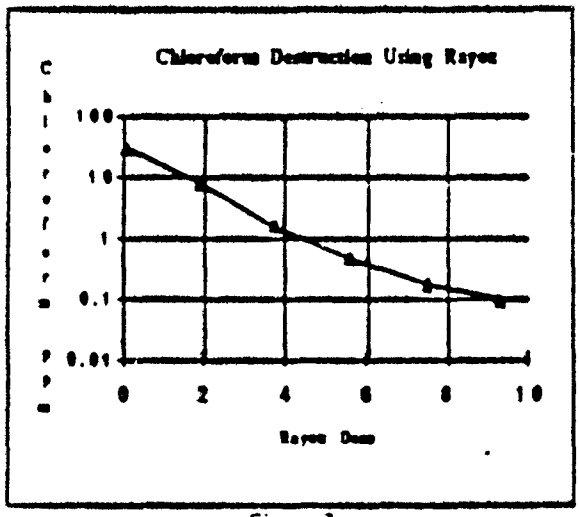

Figure 2

Figure (3) gives some results for the reduction of the TCA concentration from about 2000 ppb to less than 5 ppb.

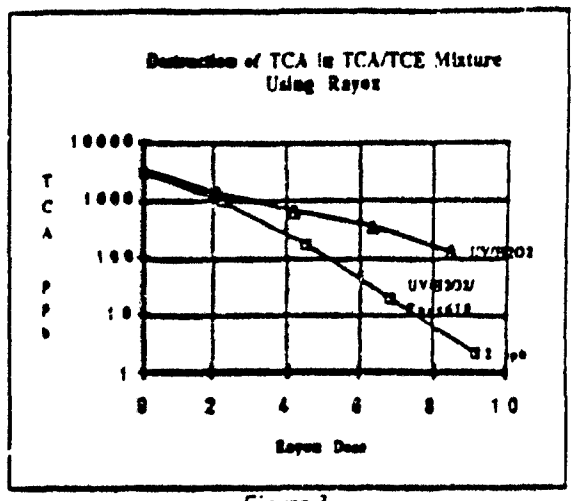

Figure 3

Figure (4) presents results showing the reduction of Freon from about 100 ppb to less than 10 ppb.

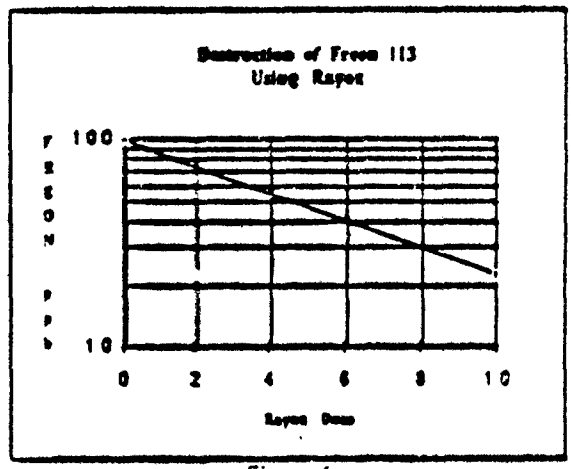

Figure 4

For each of the above examples, even lower discharge criteria could easily be achieved by simply increasing the Rayox®. dose.

Rayox® Dose

The term "dose" is defined as the summation of remediating inputs into the contaminated water such as: the amount of light, peroxide, or proprietary additives per unit volume of water treated. This dose is proportional to cost, however, it should be noted that the results given in the above figures have not been standardized to the same basis, so that a unit of Rayox®. dose in a given figure is not necessarily equal to a dose unit in another figure. This is because the cost of the different inputs (photons, peroxide,

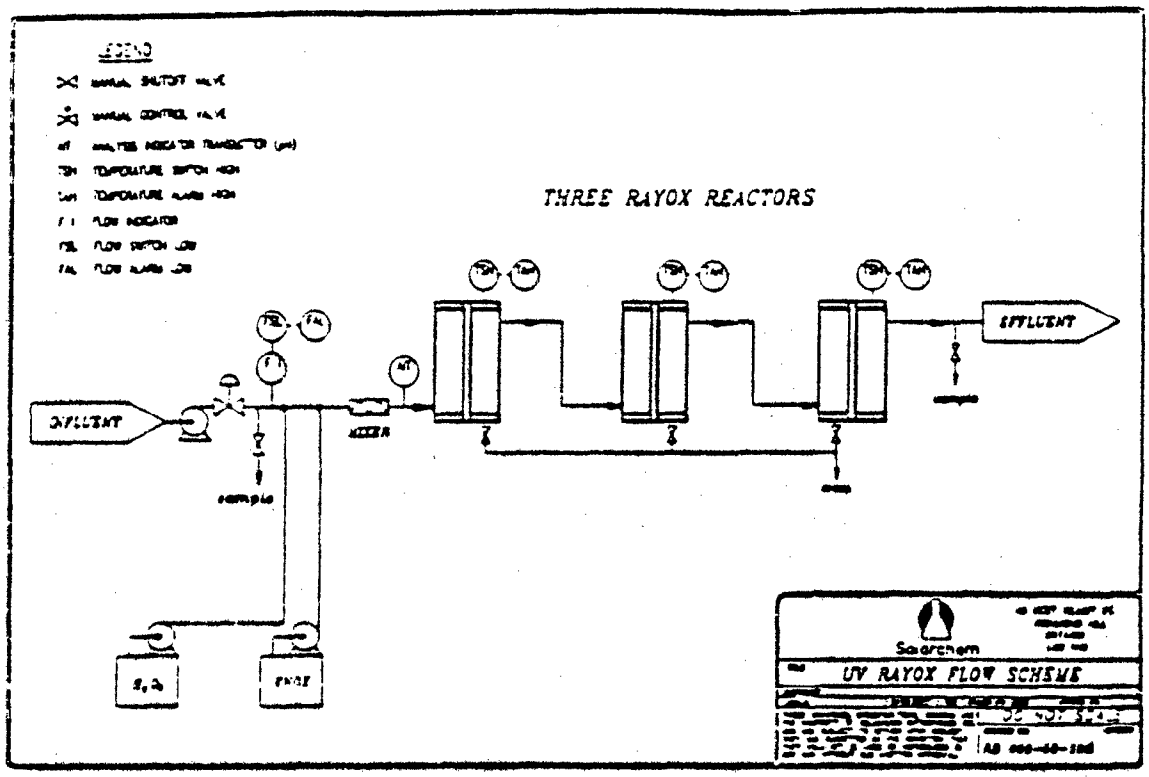

Figure 5

additives) is different and the optimum configuration of inputs varies from one type of contaminated stream to the other.

What the above results do unequivocally demonstrate is that Rayox can destroy even the most refractory waterborne contaminants and can achieve virtually any discharge criteria that might be set.

Reasons for Rayox's® Superior Performance

- A System Design that allows for Variable, Multi-stage Treatment.
- A Unique Reactor Design Which Enhances Mass and Radiation Transfer.
- The Proprietary Solarchem Lamps, and
- The ENOX Additives.

Figure (5) shows that , the basic Rayox®. water decontamination system typically consists of a series of annular reactor(s) complete with a lamp, a quartz sleeve to protect the lamp, a transmittance controller to keep the quartz sleeve clean, a variable length annulus for water flow, and a stainless steel outer wall. This design facilitates variable, multistep treatment and efficient mass and radiation transfer. The important bearing reactor design has on performance can be seen from the results shown in Figure 6A. From actual treatment results, the dioxane concentration remaining after a dose of three in reactor B is roughly one half that remaining in reactor A. Since dose is proportional to cost, it can be seen that the operational costs involved with achieving the discharge concentration obtained with 3 dose units ~0.2 ppm with reactor B would be approximately 33% more with reactor A (i.e. 4 dose units with A vs 3 units with B)

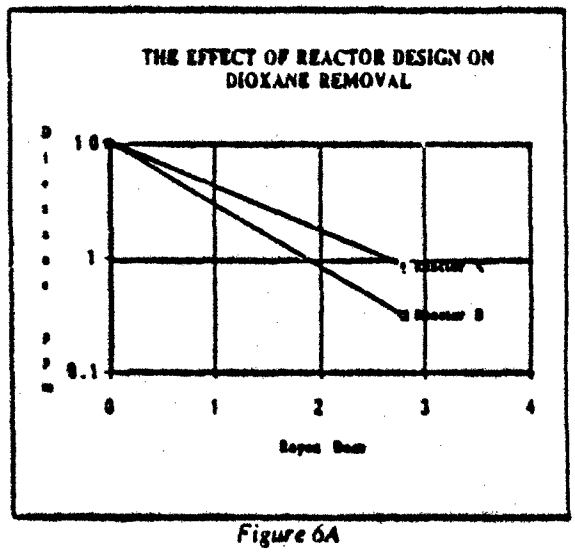

Figure 6A

The Solarchem lamps are high intensity UV light sources which have particularly strong output in the photo-active absorption bands of most waterborne contaminants. Powers 100-200 times those obtainable with low pressure mercury arcs, typical of first generation enhanced oxidation systems, are attainable with the Solarchem Lamps.

This substantial enhancement in effective power with the Solarchem lamps translates into smaller, simpler Rayox®. systems for a given throughput capacity. This, of course, becomes critically important for larger throughputs, e.g. > 100 gpm, or for more refractory contaminants such as TCA which require higher UV dosages.

The importance of the choice of UV lamp can be seen by reviewing the results given in Figure (6B). In this figure, results are shown for the destruction of waterborne dioxane as a function of dose using two different Solarchem lamps. These data show that the cost of achieving a discharge concentration of 1 ppm with lamp B would be roughly 50% that for lamp A with this particular compound.

Generally then, it is important to achieve a judicious match between the lamp emission spectrum and the photo-active absorption bands of the target contaminant(s), as this can create a significant new contaminant destruction channel i.e. photolysis or photodecomposition of the contaminant.

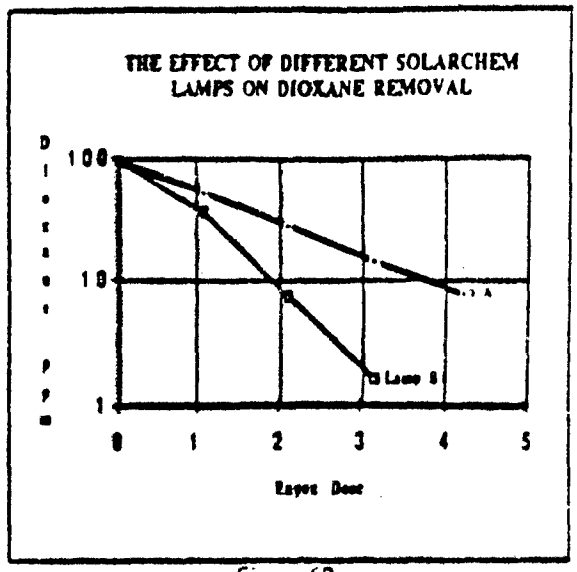

Figure 6B

A step by step reaction mechanism for the photo initiated destruction of waterborne CHC_3 is given in Figure (7). As with HO• attack on $CHCl_3$, photolysis results in the formation of a radical species ($\cdot CHCl_2$) which is transformed via a multistep process into CO_2, H_2O and Cl^-.

POSTULATED PHOTOCHEMICAL DEGRADATION MECHANISM OF CHLOROFORM[6]

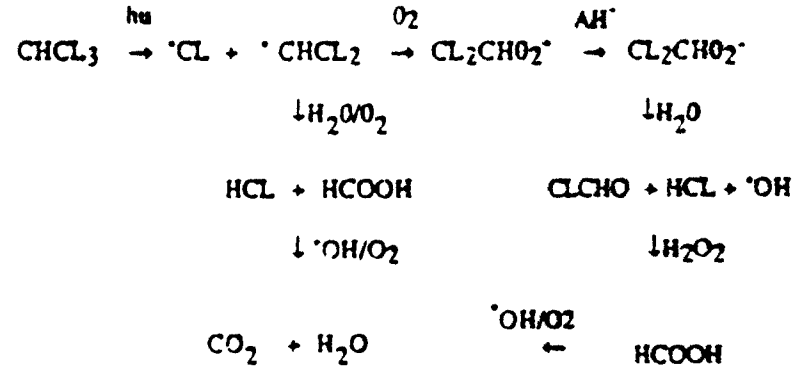

Figure 7

The final factor contributing to Rayox's®. superior performance is the use of Solarchem's proprietary ENOX additives. These additives enhance the rate of contaminant destruction by enhancing the rate of radical formation or the efficiency of radical utilization.

The extraordinary enhancement in decontamination efficiency obtained by using ENOX can be seen from

the data in Figure (8), wherein the concentration of benzene in water is plotted on a function of Rayox®. dose. From Figure (8), it can be seen that the use of ENOX 510 results in a cost one quarter (1/4) of that required for UV/peroxide alone to achieve a final benzene concentration of 1 ppb from an initial value of about 9000 ppb.

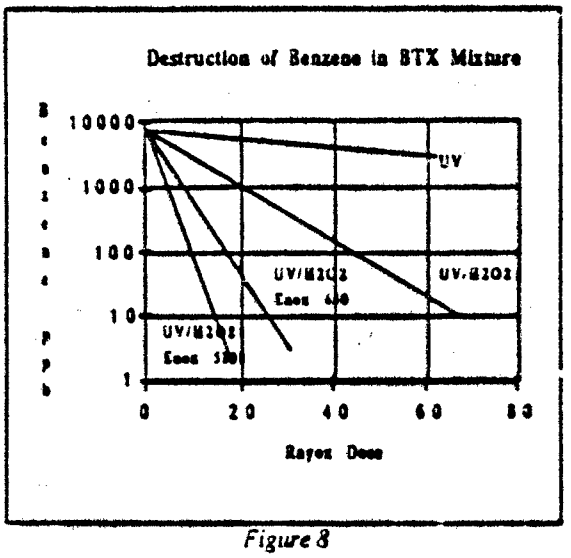

Figure 8

Groundwater Remediation Using Rayox®.

Figure (9) shows a typical transportable Rayox®. unit. This unit is capable of processing up to 30 gpm with the actual treatment capacity being dependent on factors such as influent contaminant concentrations, alkalinity, discharge criteria, etc. In most of the customer situations described below, a unit similar to this was used to develop the preferred treatment approach and final system design.

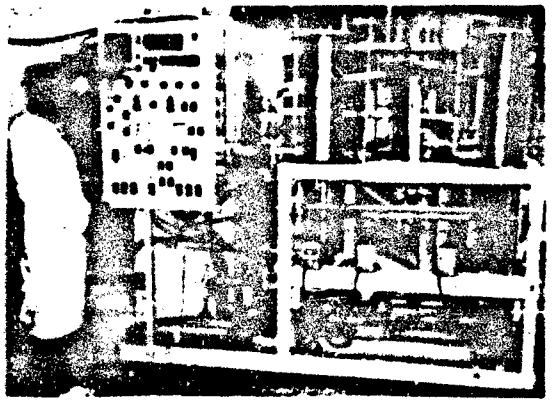

Figure 9

The chemical analysis in the work cited below were usually performed by either the customer's in house laboratory or by an independent, external laboratory hired by the customer. The analytical methodologies used were typically GC or GC/MS based with work up and operating conditions tailored to the analysis being undertaken.

1,4 Dioxane

Dioxane is an excellent, water miscible organic solvent, with a wide range of industrial applications. Unfortunately past process wastewater management practices i.e. lagoons have resulted in the contamination of some groundwater aquifers. For example, a Michigan manufacturer inadvertently contaminated an aquifer beneath one of its facilities with up to 130 ppm of dioxane.

The results shown in Figure (10) demonstrate that discharge concentrations of <2 ppb (99.999+% destruction) are readily achievable with Rayox®..

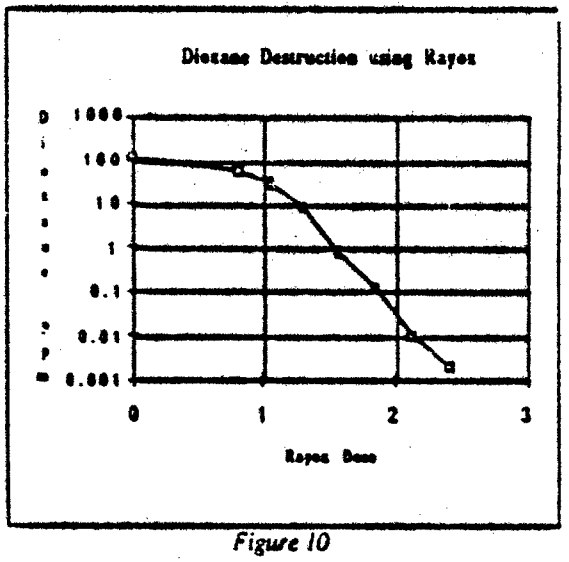

Figure 10

PCEs

Inadequate waste handling practices have resulted in the contamination of soil as well as the aquifers under a major PCB storage facility in Smithville, Ontario. The Ontario Ministry of the Environment wanted to achieve if a discharge concentration of less than 20 ppt (method detection limit). The treatment results shown in Figure (11) demonstrate that the <20 ppt target was readily attained.

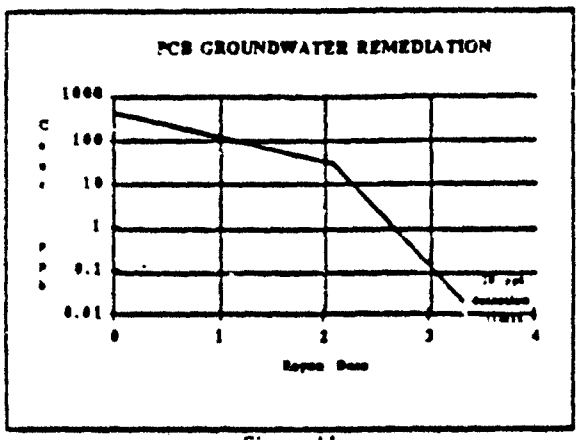

Figure 11

Benzene

The groundwater under a New Brunswick Department of Transport fueling station in New Brunswick had become contaminated over the years with BETX. As can be seen from the data in Figure (12), benzene was reduced from about 80 ppm to 1 ppb. As benzene is the most refractory of the BETX fraction, the other contaminants (ETX) were reduced to even lower concentrations.

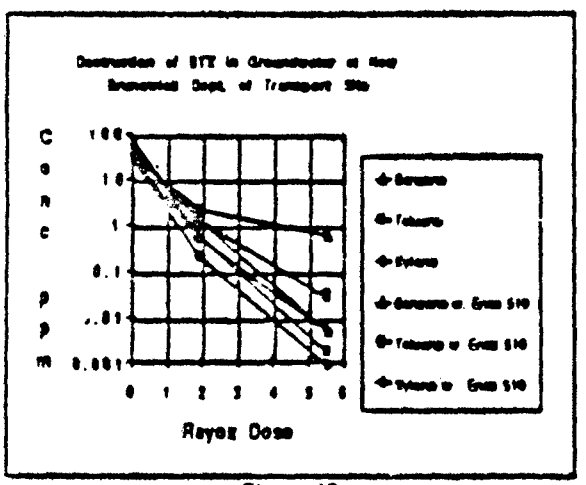

Figure 12

Another point worth noting was that no ozone was used, so there was no off gas with stripped BETX to treat. In some first generation enhanced oxidation systems, O_3 is used as a $HO^{\bullet}$ source, with the result that a significant quantity of any volatile contaminant will be air stripped due to the large gas-liquid ratio involved with such systems.

Trichloroethane (TCA)

In Figure (13), results are shown for the destruction of TCA in contaminated groundwater at a site in Sunnyvale, California. The contaminated groundwater also contains other chlorinated paraffins and olefins but the customer and their consultant were especially interested in Rayox's®. ability to decontaminate groundwater containing TCA at a concentration of a few ppm. Although TCA is refractory, the results shown in Figure (13) clearly demonstrate Rayox's®. ability to destroy waterborne TCA and achieve the design discharge criteria of less than 5 ppb.

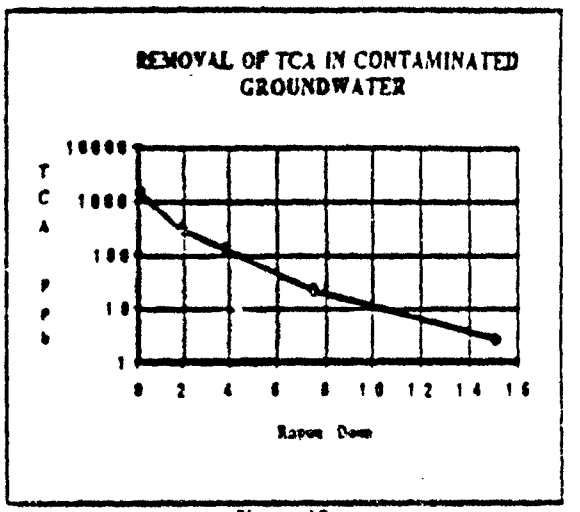

Figure 13

Pentachlorophenol (PCP)

A major Canadian wood treating firm has PCP contaminated groundwater at one of its plants in New Brunswick, Canada. The concentration of the PCP in the groundwater is about 5 ppm and the discharge criteria was set at less than 10 ppb. The results shown in Figure (14) prove that this target was easily achieved.

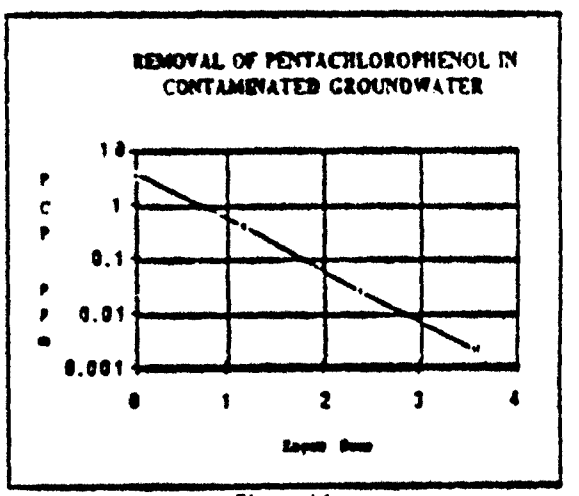

Figure 14

After processing by **Rayox®**., the treated groundwater can be directly discharged to a nearby river. Even more stringent discharge criteria could easily be met by simply increasing the **Rayox®**. dose applied to the contaminated groundwater.

A noteworthy benefit of using **Rayox®**. to decontaminate groundwater containing PCP, is that there is no secondary disposal or handling problem to deal with as a result of this treatment. This, of course, is especially important for contaminants like PCP which often contain small amounts of dioxins or furans and represent a serious disposal problem if sorbed onto carbon. Also regeneration of PCP laden carbon is becoming increasingly difficult. Thus, the use of a destruction technology like **Rayox®**. offers considerable advantages for the remediation of PCP contaminated groundwater.

A number of other examples could be cited where **Rayox®**. is becoming the treatment system of choice for on site remediation of groundwater. The data presented here are meant to be only illustrative of the breadth of application and the powerful remediation capacity of the **Rayox®**. technology.

With its significant performance advantages over earlier enhanced oxidation equipment, and over traditional non-destruction techniques, it is suggested that those with a contaminated groundwater problem consider its many benefits which include:

- Virtual zero discharge attainable at reasonable cost
  99.999+% contaminant destruction
- No secondary disposal problems
  "in stream" contaminant destruction
- De-toxifies toxic effluent streams
  Rayox®.-treated output passes biological toxicity tests & HPLC/GC toxicity scans
- Broad spectrum applicability
  virtually all organic compounds including refractories such as CCl_4, TCA, $CHCl_3$ DCA, etc. as well as fixed cyanides, hydrazines and nitrosamines
- Highly automated system
  requires essentially no operator time
- Very versatile system
  capacity can readily be turned up or down

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RAYOX®

ENHANCED OXIDATION AND REDUCTION TECHNOLOGIES FOR PHOTODEGRADATION OF ORGANIC POLLUTANTS IN WASTE STREAMS

by

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This paper was presented by J.R. Bolton, at the Symposium on Emerging Technologies in Hazardous Waste Management, Atlanta, GA in September, 1992

ABSTRACT

The use of highly efficient UV lamps, effective lamp cleaning apparatus and on-line control of the addition of chemical additives are the characteristics of Solarchem's **Rayox®** process, which involves the photolysis of H_2O_2 and other additives to achieve virtual destruction of organic pollutants in waste streams. Industrial-scale treatment includes chemical process effluent and contaminated ground water. This UV-based treatment process is also discussed in terms of the mechanism, possible intermediates and ultimate products.

There are some pollutants (e.g., chloroform) that are refractory and treat very slowly with the conventional UV oxidation treatment. Recently Solarchem introduced a new process (**Rayox®-R**) that has proved to be very effective in the removal of these refractory pollutants. Examples of **Rayox®-R** treatments are presented and mechanistic details discussed.

INTRODUCTION

Photochemical degradation processes [called Enhanced Oxidation Processes (EOP)] have almost exclusively been based on oxidative reactions initiated by very reactive radicals, such as hydroxyl radicals (•OH), which are usually generated by the photolysis of hydrogen peroxide or ozone. The hydroxyl radical attacks organic pollutants and initiates a cascade of oxidative reactions leading to mineralization of the organic pollutants. EOP systems have had good success in the treatment of waters containing pollutants, such as aromatic and olefinic compounds. However, there are some pollutants that are difficult to treat, such as haloalkanes and certain aliphatic ketones, and some companies have experienced process difficulties, such as fouling of the lamp sheaths and low UV light efficiency of lamps.

Since 1989 Solarchem has been marketing their enhanced oxidation process (**Rayox®**) and now has over 30 full-scale industrial installations in North America, Europe and Australia treating a wide variety of waste streams, including contaminated ground water (e.g., NDMA, BTEX, 1,4-dioxane), industrial process water (e.g., BTEX, chlorinated solvents, explosives) and steam distillate from the regeneration of GAC columns (e.g. MEK and toluene).

Over the past three years Solarchem has carried out an extensive development program to bring on-stream emerging technology to improve its treatment approach. This has involved not only enhancements of process dependability and efficiency, with the introduction of improved lamps, power supplies and quartz lamp sleeve cleaning systems, but also the ability to treat refractory pollutants and pollutant mixtures, with the introduction of new processes such as UV reduction (**Rayox®-R**). In this paper we outline this emerging UV treatment technology with examples of each improvement. Solarchem has 10 patents, issued or applied for, covering these developments.

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ENHANCED OXIDATION PROCESSES

Enhanced Oxidation Processes (EOP) [also called Advanced Oxidation Processes (AOP)] [1,2] are capable of converting pollutants into harmless chemicals. They are called oxidation processes because they promote reactions that bring about a nearly complete oxidation (or mineralization) of pollutants to yield HCO_3^-, H_2O and a small amount of acid from any halogens, nitrogen or sulfur present. For example, 2,4-dichlorophenol ($C_6H_4OCl_2$) reacts according to

$$C_6H_4OCl_2 + 5\,H_2O + 6\,O_2 \rightarrow 8\,H^+ + 6\,HCO_3^- + 2\,Cl^-$$

In some cases the UV light is absorbed directly by the pollutant [e.g., N-nitrosodimethylamine (NDMA)] leading to its oxidative degradation. However, in most cases a UV absorber must be added to initiate the mineralization reactions. The principal absorbers utilized have been hydrogen peroxide and ozone. H_2O_2 undergoes the photolysis reaction

$$H_2O_2 \xrightarrow{h\upsilon} 2\,\cdot OH$$

at wavelengths below ~320 nm with a quantum yield of about 1.0 per •OH radical generated. Since H_2O_2 absorbs much more strongly at shorter wavelengths (<250 nm), this additive is particularly suited to the spectral output of Solarchem's UV lamps.

Ozone also photolyzes to eventually yield •OH radicals; however, the efficiency is not as high as with H_2O_2, and there is the added capital cost of an ozone generator. However, there are situations where ozone is the preferred additive, especially where O_3 can react directly with the pollutant.

Once •OH radicals are generated, from whatever source, they readily attack most organic pollutants. Aliphatic compounds react by hydrogen abstraction to yield water and an organic radical; aromatic and olefinic compounds react by addition of the •OH radical to double bonds. The resulting organic radicals then react rapidly with dissolved oxygen, and a sequence of largely autocatalytic spontaneous oxidative reactions is initiated leading ultimately to complete mineralization.

The treatment rate for a given pollutant (or mixture of pollutants) can vary considerably, depending on the pollutant composition, the turbidity of the water and any inhibitors that might be present. Thus Solarchem has found it useful to introduce a "figure of merit", called the Electrical Energy per Order (EE/O) to evaluate EOP. Since the rate of photodegradation of a pollutant usually follows first-order kinetics, this means that every decade in reduction of pollutant concentration requires the same time and hence the same amount of UV irradiation. Thus the EE/O is defined as the electrical energy required to reduce the concentration of a pollutant by one order of magnitude in 1000 US gallons (3785 L) of water. In favorable cases, the EE/O can be as low as 2-5; a large variety of pollutants treat with EE/O values in the range 10-15; however, there are some pollutants (haloalkanes, some aliphatic ketones, some nitroaromatic compounds) that are difficult to treat having EE/O values from 20 to over 100. The EE/O may be calculated from the equations:[2]

$$EE/O = \frac{P \times (t/60) \times 3785}{V \times \log(c_i/c_f)} \quad \text{(Batch Experiments)}$$

$$EE/O = \frac{P \times 1000\ \text{gallons}}{R \times 60 \times \log(c_i/c_f)} \quad \text{(Flow through Experiments)}$$

Where P is the lamp power in (kW), t is the irradiation time (in minutes), V is the reactor volume (in litres), R is the flow rate (in gal min^{-1}), and c_i and c_f are the initial and final concentrations over the irradition time. The EE/O values are related to the first order rate constant k_1 (min^{-1}) by

$$EE/O = \frac{145.25\,P}{V \times k_1}$$

The EE/O values can increase considerably with the presence of particulate matter and inhibitors and with process conditions, such as flow rate. Some of these factors are addressed in this paper. Many EOP and AOP results are now given in the literature and at conferences, but the lack of standard reporting conditions makes comparisons difficult. We strongly recommend that a common evaluation measure, such as EE/O, be adopted.

PROCESS IMPROVEMENTS

1. *UV Lamps and Power Supplies:*

Most UV photodegradation processes occur with the absorption of UV light in the 200 - 300 nm range. However, commercially available high power UV lamps have an energy efficiency of only ~15%. In co-operation with our lamp supplier, we have been

able to improve this efficiency to over 30%, with a substantial output below 240 nm, where many pollutants absorb UV directly. As an example, Figure 1 compares the treatment under identical conditions of pollutant concentration, flowrate and temperature of 1,4-dioxane, dichloromethane, and pentachlorphenol with Solarchem's 1 kW lamp and a commercial 450 W medium pressure mercury lamp. As can be seen, the efficiency of Solarchem's lamp is two to three times greater than the standard commercial lamp, even when allowance is made for the different electrical powers. **Rayox®** systems use these lamps in 5, 10 and 30 kW sizes. Note also that dichloromethane treats most slowly. This is one of the refractory pollutants that we address in the section on **Rayox®-R**. Figure 2, showing UV absorption spectra of several typical pollutants from 200-300 nm demonstrates why an effective EOP treatment is enabled by a lamp with correctly placed UV emission.

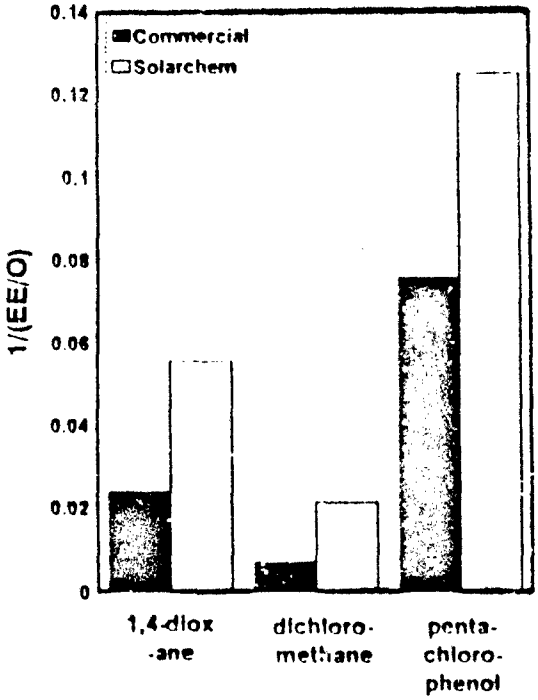

Figure 1
Comparison of inverse EE/O values (lower EE/O means more efficient treatment) for a commercial 450W medium pressure Hg lamp and a 1 kW Solarchem lamp.

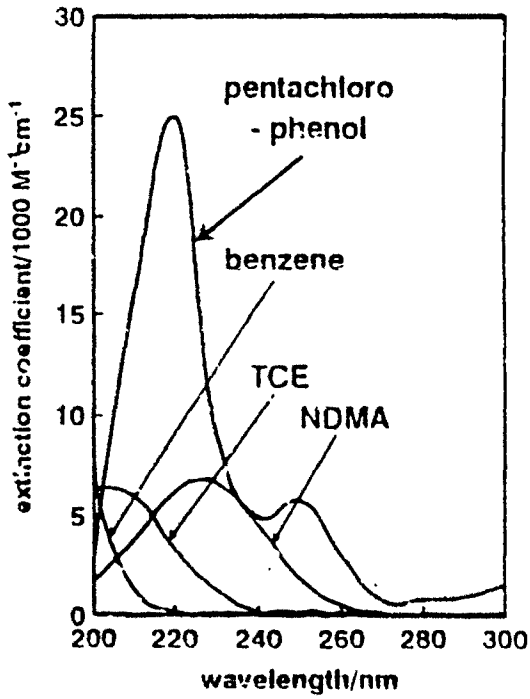

Figure 2
UV absorption spectra of several typical organic pollutants.

Enhanced oxidation is an energy intensive method of water treatment. Use of an energy efficient power supply has positive consequences on the operating costs of commercial systems. For this reason, Solarchem's developmental efforts on lamp power supplies have centered on achieving an excellent match between the inductive load represented by the lamp and the power supply (referred to in some literature as the ballast). Over 90% of the mains power delivered by the power supply is received by the lamp. Power factor correction produces a power factor better than 0.9, thus avoiding a potential low power factor surcharge by the utility.

2. *UV Reactor and Transmittance Controller:*

The **Rayox®** reactor has a single UV lamp at the center separated from the water by a cylindrical quartz sleeve. A typical flow-through configuration for three reactors is shown in Figure 3. The use of multiple reactors in series introduces the possibility that each one can use a different EOP or UV reduction treatment. A further description of some applications of this feature is given in the section on **Rayox®-R**. With this type of reactor, fine control of addition of reagents, including between-reactor injection, is enabled. Injection rate of reagents such as hydrogen peroxide or of proprietary additives is one key to

obtaining optimum performance. A UV path length appropriate to the specific absorbance characteristics of the water is the ideal way to obtain maximum utilization of photons. Rayox® reactors, varying in path length from about 3" to 8", can, when required, be grouped together in the same treatment train. For waters of very high absorbance, mixing techniques direct the water to the space immediately adjacent to the quartz.

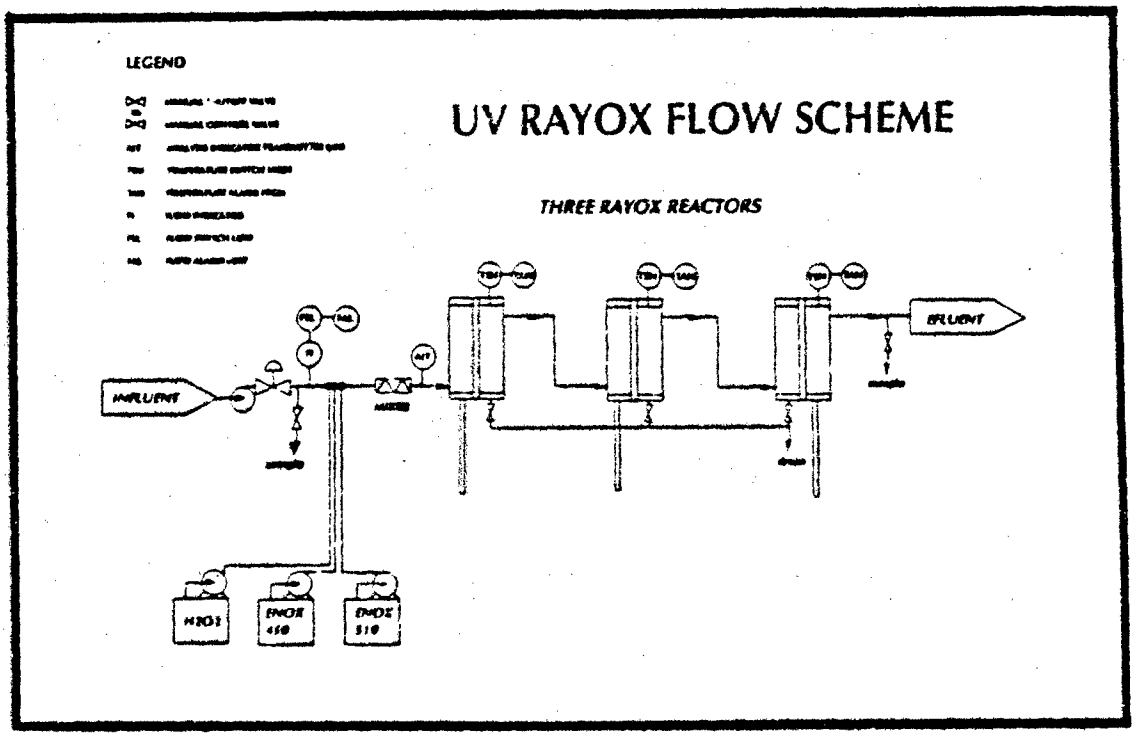

Figure 3

Flow through configuration for a 3-reactor Rayox® system. The untreated waste water enters on the left and is discharged as treated water on the right.

Referring again to Figure 3, note a vertical tube, off center and just below each reactor. This represents the patented cleaner (called transmittance controller) for the quartz sleeve around the lamp. This device consists of a concentric stainless steel brush assembly that is automatically driven over the surface of the quartz sleeve by a pneumatically driven impeller.

UV light catalyzes the deposition of metal oxide coatings on the quartz sleeve.[3] Iron-containing groundwaters are a particular problem. Without the transmittance controller, treatment efficiency may be very good at first, but deteriorate over a period of weeks, months, or even days.

Figure 4 illustrates two quartz sleeves exposed to iron-containing groundwater. The one without the transmittance controller severely blocks the UV after less than 6 hours of treatment. Figure 5 shows the performance of a Rayox® groundwater installation, running at 500 gpm, for 32 weeks. This was possible only as a result of the installation of the transmittance controller on each reactor.

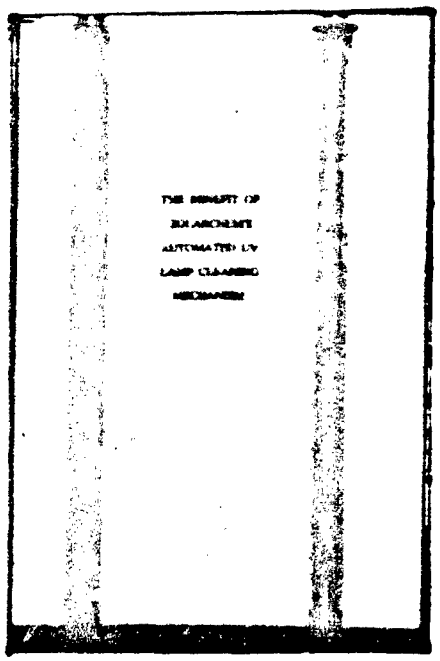

Figure 4

Photograph of two quartz sleeves maintained in a Rayox® reactor where an iron containing groundwater was treated. The reactor with the sleeves on the left operated for less than 6 hours without the transmittance controller; the sleeve on the right came from a reactor with an operating transmittance controller after more than 6 hours of treatment

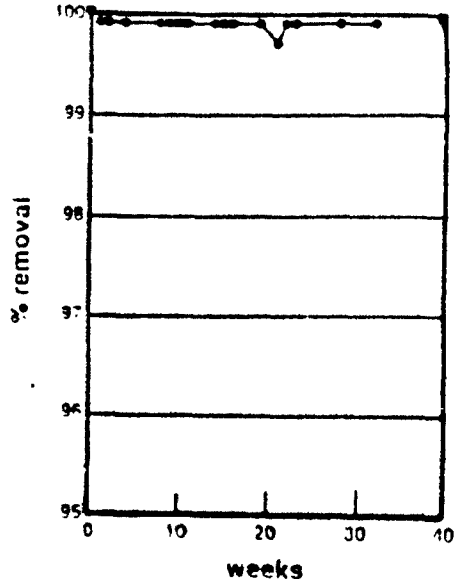

Figure 5

Operating results for a Rayox® groundwater installation equipped with a transmittance controller.

Figure 6 is an illustration of a 9-reactor Rayox® installation. Each reactor contains a Solarchem 30 kW lamp, with power supply adjacent to the reactor. Note the master control unit, on the first skid of three reactors. The entire system is fully automated and failsafe. In this system, the most common Rayox® reactor size, 14" diameter is used.

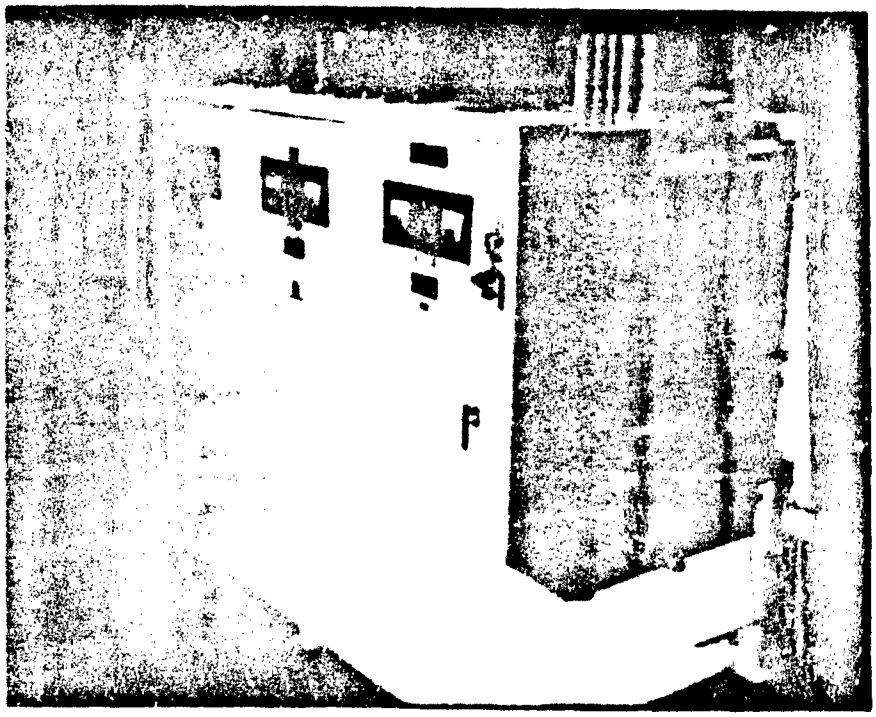

Figure 6

Photograph of a 9-reactor Rayox® installation mounted on three skids, with the master control unit on the first skid

3. *Rayox® Process:*

Rayox® is the most mature of treatment processes that Solarchem offers. In a typical flow through installation 5-100 gpm of contaminated water is passed through 1-3 30 kW UV reactors. Hydrogen peroxide and other proprietary (ENOX) additives are injected into the water before the first reactor, and in some cases in-between reactors. Efficient mixing baffles assure that the UV light reaches all parts of the solution equally.

Figure 7 illustrates the application of **Rayox®** technology to a groundwater contaminated with nitrosodimethylamine (NDMA). In this case, no additives are required as NDMA undergoes direct photolysis with an excellent EE/O value of 2.5. As a result of local hydrogeology, the influent concentration of NDMA spans at least one order of magnitude. Typical treatment results show that the first order rate constant of the EOP, *i.e.*, slope of the graph, is independent of the initial concentration.

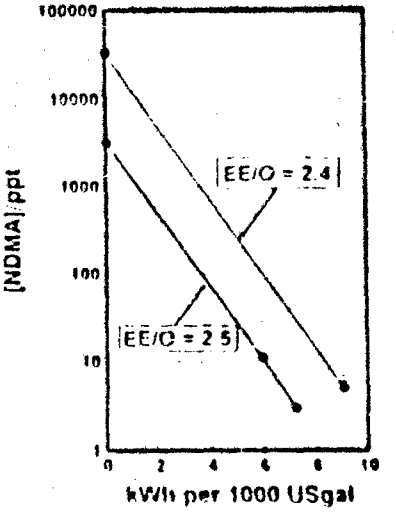

Figure 7

***Rayox®** treatment of a groundwater containing 3000 ppt of N-nitroso-dimethylamine (NDMA). This process does not require any additives.*

Figure 8 gives an example of the use of **Rayox®** to treat an industrial process water containing VOCs [principally trichloroethylene (TCE), 1,2 dichloroethylene (DCE) and vinyl chloride (VC)]. As seen in the figure all three treat very well with EE/O values of ~10. The transmittance controller is particularly valuable in this application because of the exceptionally high iron content of the water, *i.e.*, 100 ppm.

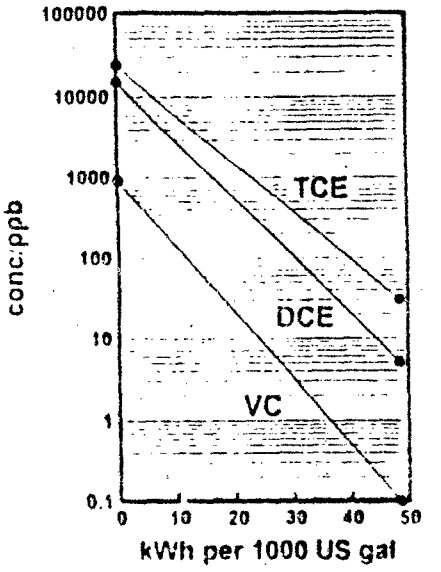

Figure 8

***Rayox®** treatment of an industrial process water containing VOCs: 2500 ppb trichloroethylene (TCE), 1500 ppb 1,2-dichloroethylene (DCE), and 900 ppb vinyl chloride (VC) together with 100 ppm of iron, 200 ppm of H_2O_2 was added at the beginning.*

4. *Effect of Particulates:*

Many waste streams are loaded with particulates, ranging from very fine particles (<10 nm diameter) to coarse particles (>10 nm diameter). The suspended solids may absorb light and thus block photons from initiating the photo-degradation of the target contaminants. In addition, they can also: (a) change the dielectric constant and the refractive index of the solvent which can change the quantum efficiency and reaction rate constants; (b) react with hydroxyl radicals and thus act as a sink for •OH radicals; (c) absorb hydrophobic pollutants, such as PCB's and PAH's and; (d) scatter light. The overall effect of all of these is the reduction of the treatment efficiency.

We have studied the effects of suspended solids by spiking tapwater with *bentonite*, a natural clay. In some experiments, the bentonite was coated with ferric hydroxide. The influence of these suspended solids on the destruction of chlorobenzene is shown in Figure 9. Bentonite does not absorb UV light and thus by itself has very little effect on the treatment of chlorobenzene. However, the destruction rate of chlorobenzene is reduced by about a factor of two when bentonite is coated with light absorbing iron hydroxide from a solution that contained ~10 ppm Fe^{3+}.

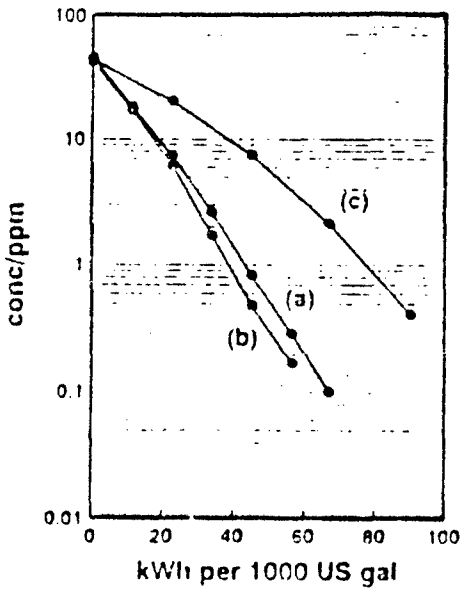

Figure 9

Rayox® treatment of 40 ppm chlorobenzene: (a) without suspended solids; (b) bentonite (200 ppm) added; (c) same as (b) but with 10 ppm Fe^{3+} at pH 7.

5. ***Rayox®-R:***

As stated in the Introduction, there are some *refractory* pollutants that treat slowly (EE/O > 20). Halogenated alkanes (e.g. methylenechloride (DCM), chloroform, carbon tetrachloride, 1,1,1-trichloroethane (TCA), 1,1,2,2-tetrachloroethane (QCA), Freon-11 ($CFCl_3$), Freon-113 ($CFCl_2CF_2Cl$), 1,2-dibromoethane (DBA), etc.) represent a major class of refractory pollutants. These compounds are difficult to oxidize and thus should be easy to reduce.

Over the past year Solarchem has invented and developed Rayox®-R, a new UV *reduction* process (patent applied for) based on the photolysis of ENOX 710 to generate *hydrated electrons* e^-_{aq}, one of the most powerful reducing agents known ($E^0 = -2.9$ V). ENOX 710 is a Solarchem proprietary additive.

Figure 10 compares the treatment of chloroform using Rayox® (UV/H_2O_2) and Rayox®-R, with the latter showing a rate improvement of over four times.

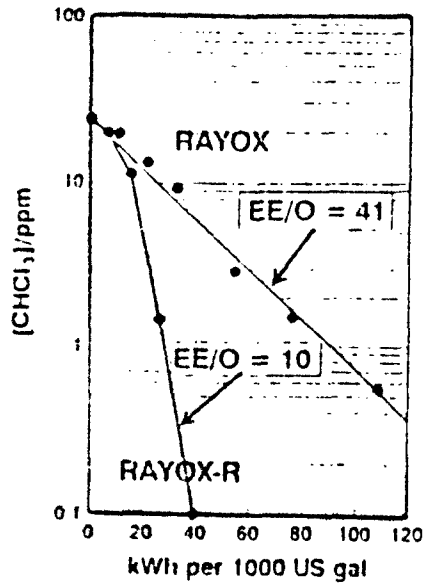

Figure 10

Comparison of Rayox® and Rayox®-R in the treatment of 20 ppm chloroform in tapwater.

We have carried out some mechanism studies and have identified CCl_2HCCl_2H (QCA), $CCl_2=CClH$ (TCE) and ClHC1=CHC1 (DCE as intermediates. On the basis of this and other evidence we propose the following mechanism

$$\text{ENOX-710} \xrightarrow{h\nu} e^-_{aq} + H^+$$

$$e^-_{aq} + CHCl_3 \longrightarrow {}^\bullet CHCl_2 + Cl^-$$

$$2\ {}^\bullet CHCl_2 \longrightarrow CCl_2HCCl_2H \quad (QCA)$$

$$e^-_{aq} + CH_2CCl_2H \longrightarrow {}^\bullet CClHCCl_2H + Cl^-$$

$$2\ {}^\bullet CClHCCl_2H \longrightarrow CClH{=}CCl_2 + CH_2ClCCl_2H \quad (TCE)$$

$$e^-_{aq} + CH_2ClCCl_2H \longrightarrow {}^\bullet CClHCH_2Cl + Cl^-$$

$$2\ {}^\bullet CClHCH_2Cl \longrightarrow ClHC{=}CHCl + CH_2ClCH_2Cl \quad (DCE)$$

In support of this mechanism, we find that H^+ is produced in equivalent amounts to that of chloride. Also we are able to recover over 90% of the initial organic chlorine as inorganic chloride.

Rayox®-R is a process in which the hydrated electrons progressively dehalogenate the target compound. We believe that the ultimate products are non-toxic non-halogenated organic acids, such as acetic acid and oxalic acid.

It is possible to treat sequentially with **Rayox®-R** and **Rayox®**. Figure 11 shows the treatment of a mixture of 1,1,1-trichloroethane (TCA) and toluene. In the **Rayox®-R** phase the TCA disappears rapidly, but the toluene hardly changes at all. Then in the **Rayox®** phase, the toluene, plus any products from the treatment of the TCA, are removed. This example demonstrates the versatility of the treatment options available.

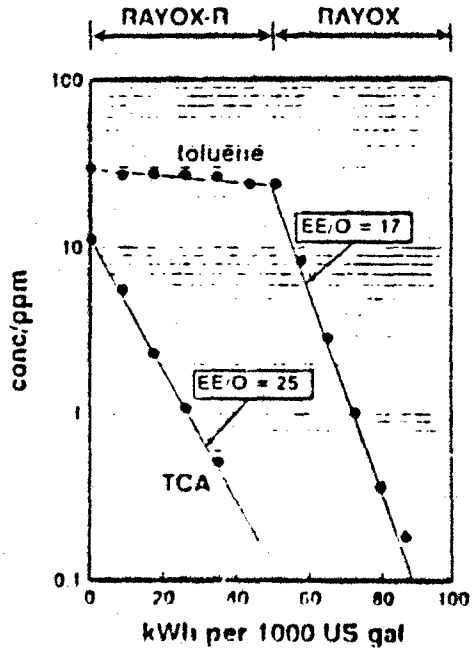

Figure 11
Treatment of 50 ppm TCA and 20 PPM toluene in tapwater sequentially with Rayox®-R and then with Rayox®.

CONCLUSIONS

The development program described in this paper has enabled Solarchem to bring on-stream much of the technology to emerge from its R & D efforts. The improvements can be summarized as follows:

1. The development of UV lamps which have an electrical efficiency of over 30% for th emission of UV light in the 200-300 nm range.

2. Design and implementation of power supplies with over 90% efficiency in delivering electrical power to the UV lamps.

3. Invention of a patented transmittance controller for keeping the quartz sleeve clean.

4. Application of **Rayox®** EOP technology to a variety of industrial process waters and contaminated ground waters in over 30 full-scale installations.

5. Study of the effect of particulates on the efficiency of EOP treatments.

6. Invention of a new and effective UV reduction technology (**Rayox®-R**) for the treatment of refractory halogenated alkane pollutants.

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2. J. R. Bolton and S. R. Cater, "Homogeneous Photodegradation of Pollutants in Contaminated Water: An Introduction" in *Environmental Aspects of Surface and Aquatic Photochemistry*, D. Crosby, R. Zepp and G. R. Helz, Eds, CRC Press, Boca Raton, FL, (in press).

3. S. Egli, S. LoMonto, R. Galli, R. Fitzi and C. Munz, "Oxidative Treatment of Process Water in a Soil Decontamination: II Pilot Plant and Large Scale Experiences" in Chemical Oxidation Technologies For The Nineties, Second International Symposium, Vanderbilt University, 1992.

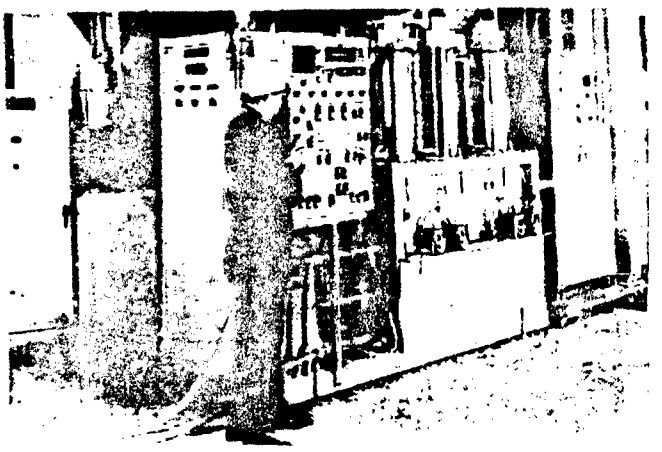
RAYOX®

Second Generation Enhanced Oxidation Process for the Destruction of Waterborne Contaminants

GROUNDWATER REMEDIATION
1,1,1 TRICHLOROETHANE (1CA)

THE PROBLEM

A groundwater aquifer had been inadvertently contaminated with about 2 mg/l. (ppm) of the refractory chlorinated solvent 1CA. The customer is currently using aeration towers ("air strippers") to remediate the groundwater but is seeking an alternative due to increasingly stringent regulatory controls on the off gases from the air stripper. The customer requested an on site demonstration that Rayox could achieve a discharge criterion of less than 5(ug/l. (ppb).



Rayox Demonstration Unit

THE SOLUTION

A skid mounted, transportable Rayox demonstration unit was shipped to the customer's site and carried out a series of trials using different Rayox process configurations (dosage of light, peroxide, ENOX additives, etc.) directed towards finding the least cost solution for the customer.

Typical test results are shown in Figure 1. It can be seen that from these data that the most stringent customer requirement can easily be met including the discharge criterion of less than 5 ppb with no downstream disposal requirements.

In consultation with the customer, an evaluation of important factors such as capital amortization schedule, interest rates, capital and operating costs provided the information necessary to select the least cost Rayox solution for the problem.

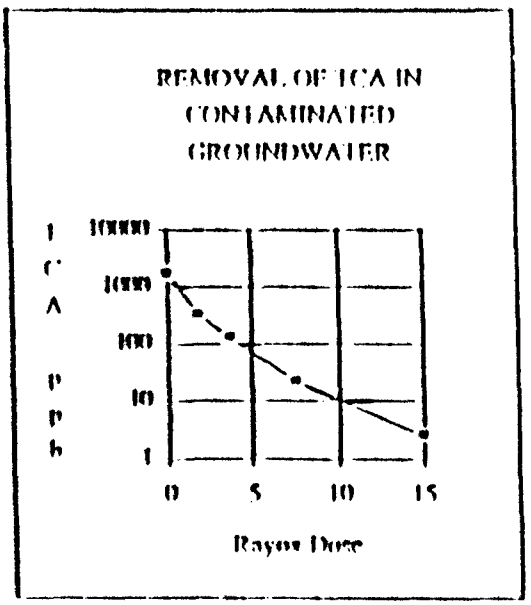


Figure 1

Have a problem with 1CA contaminated groundwater?

Contact Solarchem's groundwater remediation specialists to find out how Rayox can help you.

SOLARCHEM ENVIRONMENTAL SYSTEMS

130 Royal Crest Court
Markham, Ontario
Canada L3R 0A1
Telephone (416) 477-9242
Fax (416) 477-4511

7320 Smoke Ranch Road, Suite H
Las Vegas, Nevada, 89128
USA
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Fax (702) 255-7280

CH2MHILL

TECHNICAL MEMORANDUM M(b)

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Peter Rude/CH2M HILL, Redding
Gerald Vogt/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Groundwater End-Use Components
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.13

Purpose and Scope

This technical memorandum develops and evaluates five potential end-use components that would provide a beneficial use for treated groundwater from the Davis Global Communications Site (Davis Site). A remedial action will be implemented to contain the horizontal and vertical extent of the groundwater contamination and to begin removal of the highest concentrations of groundwater contamination. The remedial action consists of a groundwater extraction system, a treatment system, and an end-use system. This technical memorandum provides supplemental information for the Remedial Investigation/Feasibility Study (RI/FS).

The end-use system options include Wilson Park irrigation, Wallace Farms irrigation, surface-water discharge to Putah Creek, onsite groundwater reinjection, and onsite irrigation.

This technical memorandum presents the following design issues associated with all five end-use components:

- Treated groundwater characteristics
- Site descriptions
- Water usage
- Storage and water distribution facilities
- Institutional issues
- Estimated capital costs

The following two issues were developed for the preferred end-use components (groundwater reinjection and Wallace Farms irrigation):

- System operations

- Estimated annual costs

In addition, the estimated capital and annual costs are presented for the groundwater extraction system described in Appendix J, Groundwater Modeling (Microfem).

Treated Groundwater Characteristics and Flow Rates

The water supply for each of the end-use components is groundwater pumped from below the site and treated onsite to remove volatile organic compounds (VOCs). Other than the presence of VOCs, the groundwater characteristics are expected to be the same as those being used for irrigated agriculture in the area surrounding the Davis Site.

The flow rates of the treated groundwater will vary depending on the extent of groundwater contaminant removal. For this evaluation, two flow-rate scenarios were developed:

- **Scenario No. 1**—Groundwater is pumped 12 months per year at a rate of 380 gallons per minute (gpm) from the B and C aquifers. This flow-rate scenario is equivalent to approximately 610 acre-feet of water per year, or 250 acre-feet November 1 through March 31, and 360 acre-feet from April 1 through October 31.

- **Scenario No. 2**—Groundwater is pumped 12 months per year at a rate of 820 gpm from the B, C, D, and E aquifers. This flow-rate scenario is equivalent to approximately 1,320 acre-feet of water per year, or 550 acre-feet November 1 through March 31, and 770 acre-feet April 1 through October. 31.

The growing season in the area has been defined as April 1 through October 31. These flow-rate scenarios provide the basis for developing facility requirements and estimating capital costs.

End-Use Components

Option 1—Wilson Park Irrigation

Site Description

Wilson Park is adjacent to the western border of the Davis Site. The park consists of 320 acres that was deeded from the Air Force to Yolo County in 1973. Approximately 60 acres of the park have been leased to an archery club, a horseshoe club, and a dog training club. The remaining land is undeveloped grassland.

Yolo County has developed a master plan for the park, which is presented in Figure M(b)-1. As shown on the plan, the majority of the park (170 acres) will remain in native grasslands and oak trees. One reason that the park has remained largely undeveloped is due to the lack of a water supply for irrigation.

Water Usage

The land use categories, associated estimated acreages, and estimated water usage are presented in Table M(b)-1. The water usage was developed following the Wilson Park plan to drip irrigate oak tree seedlings during establishment only. In addition, the water usage of 85 acre-feet of water for the ponds and lakes was assumed to be evaporation losses, with no losses due to seepage. The park will require approximately 275 acre-feet of water for the 7-month growing season. This is equivalent to an average daily flow rate of approximately 300 gpm.

Table M(b)-1
Estimated Water Use for Wilson Park
From April to October

Land Use	Area (acres)	Estimated Water Usage (acre-feet)
Turfgrass	15	45
Orchard Trees	30	65
Oak Trees	170	10
Archery Range	15	15
Lake and Ponds (Evaporation)	25	85
Miscellaneous	55	55
Total	320	275

The water usage of 275 acre-feet can be supplied by both flow scenarios; however, another reuse option would be required to use the remaining flow.

Water Distribution Facilities Required

The facilities required to provide treated groundwater to the north central border of Wilson Park are listed in Table M(b)-2. The facility sizes do not vary between the groundwater pumping scenarios because the demand is less than the supply. The distribution pump was sized to deliver water at 5 pounds per square inch (psi). A low delivery pressure was used assuming that the water would be discharged into a lake or pond at the park and that the park would have its own irrigation pump. The distribution pipeline was sized to keep water velocities below 5 feet per second (fps).

In addition to the facilities listed in Table M(b)-2, the system would require telemetry control from the treatment plant to the discharge point at Wilson Park. The telemetry is required for regulating the flow of water and automating pump operations.

Figure M(b)-2 provides a conceptual layout of the major facilities required to provide water to Wilson Park.

Table M(b)-2
Facilities Required at Wilson Park

Facilities		Groundwater Pumping Scenarios	
		No. 1	No. 2
1.	Distribution Pump Station		
	- Design Flow (gpm)	380	380
	- Total Dynamic Head (ft)	155	155
	- Delivery Pressure (psi)	5	5
	- Motor Size (hp)	25	25
2.	Distribution Pipeline		
	- Diameter (in.)	6	6
	- Length (ft)	6,000	6,000

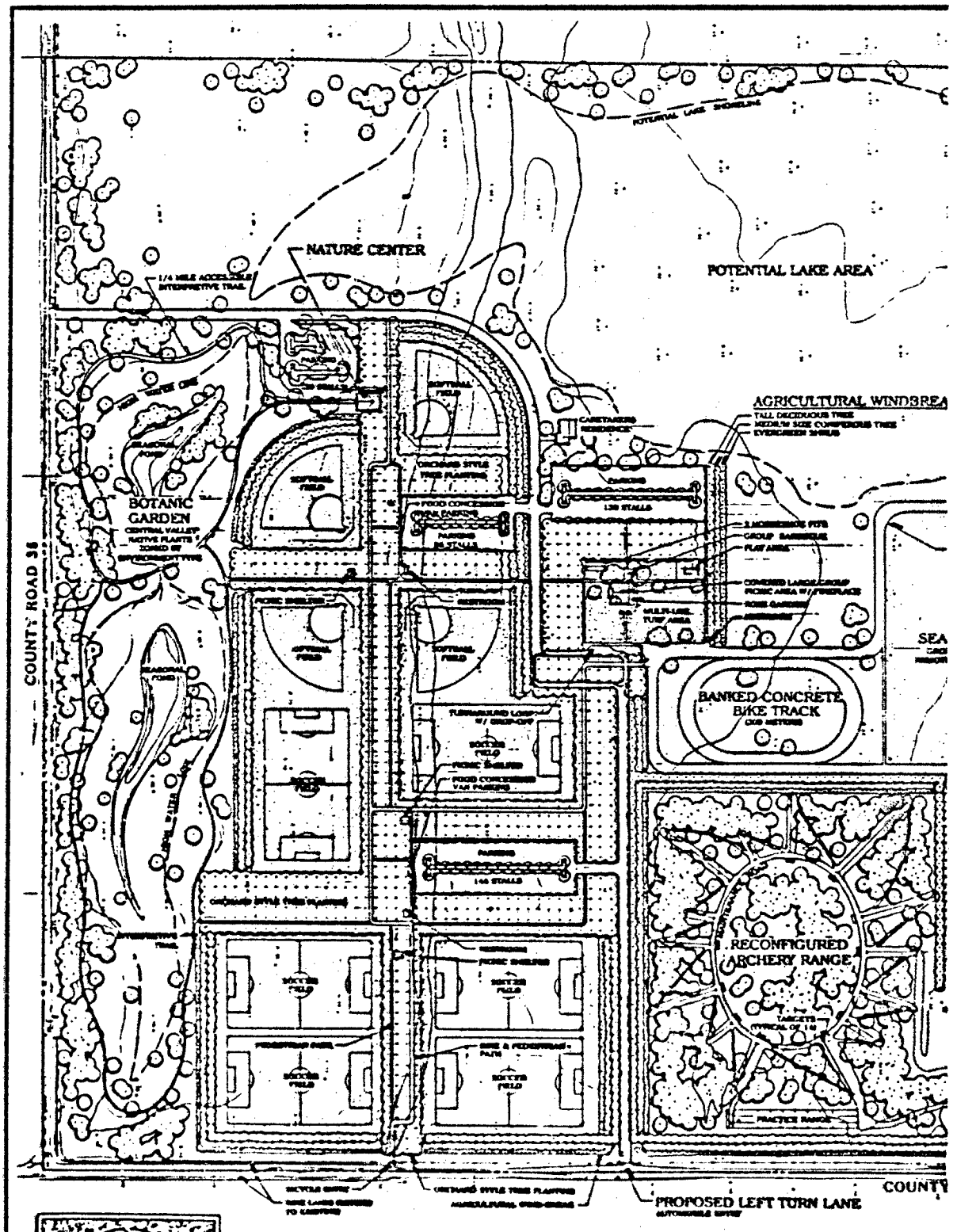
Institutional Issues

One constraint against having Wilson Park as an end-use option is that the park is currently undeveloped. It may be several years before the park could use 275 acre-feet of treated groundwater. The Yolo County Facilities and Administrative Services has indicated that a readily available water supply would likely speed up efforts to develop the park.

A Report of Waste Discharge will be required by the Regional Water Quality Control Board (RWQCB). The report will require the submittal of the project design information and a location map. Once information is submitted to the RWQCB, a permit should be issued within 6 months.

A user agreement should be developed and signed for the understanding and protection of both McClellan Air Force Base (McClellan AFB) and Yolo County. The agreement should include the following basic provisions:

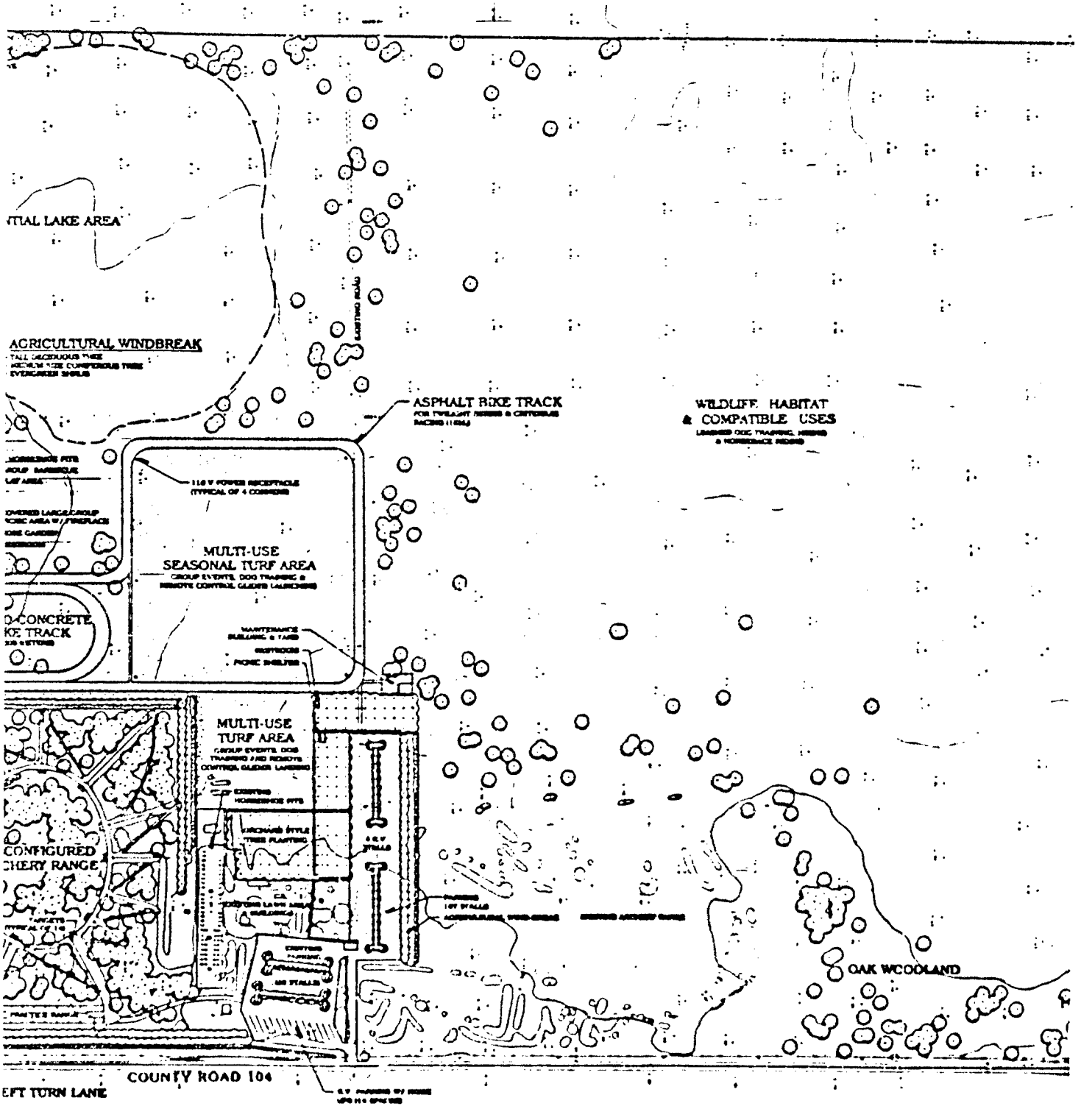
- The length or term of the agreement
- The price of the treated water
- Conditions for termination for both parties
- Treated water quality guarantee
- Treated water use requirements
- Methods and limitations of delivery of treated water
- Mutual liability considerations
- Right of entry
- Other general considerations



EARTH·ART

GRAPHIC S

NOTE: MASTER PLAN WAS PREPARED BY EARTH ART, SACRAMENTO, CALIFORNIA, FOR YOLO COUNTY.



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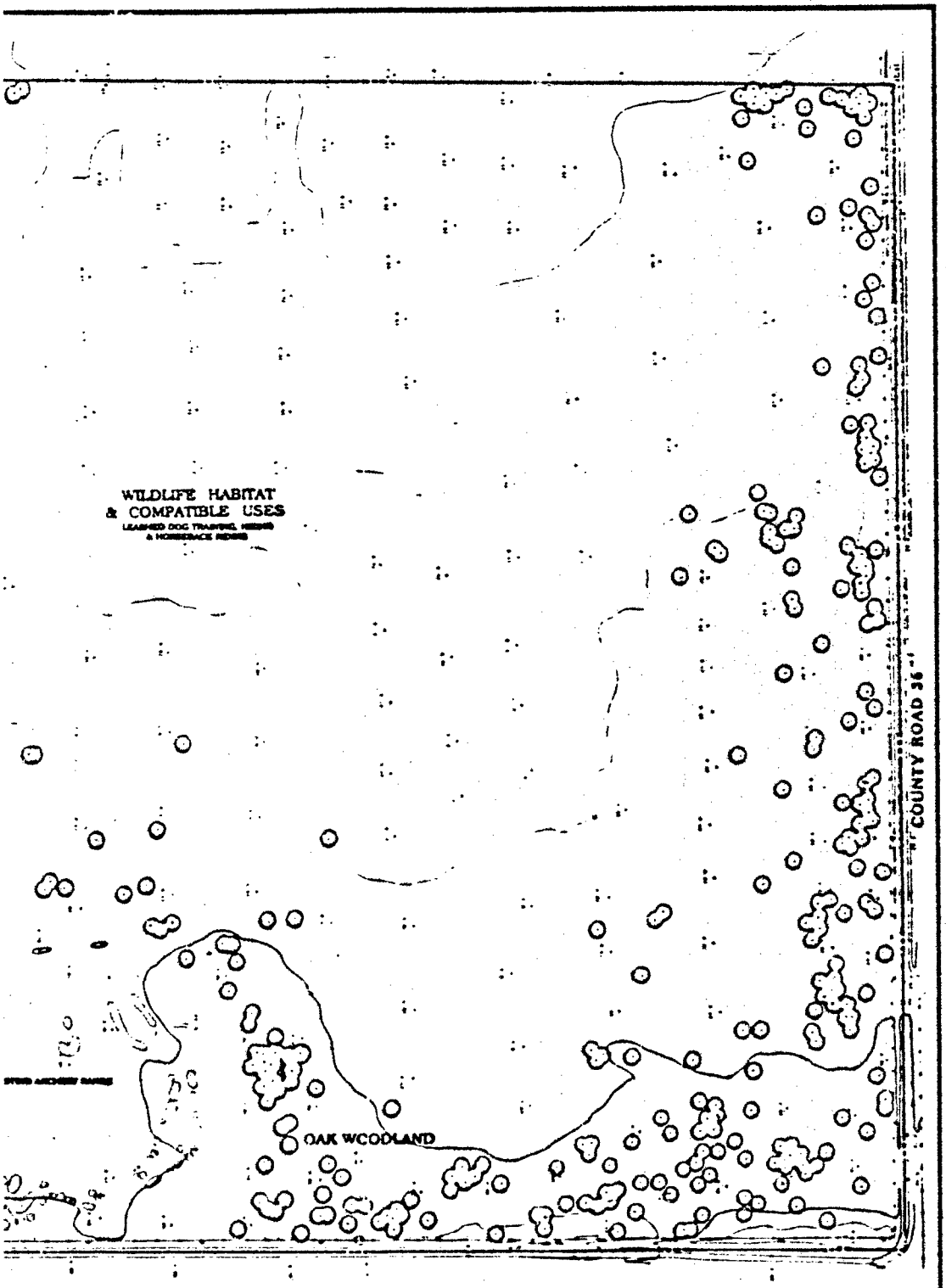
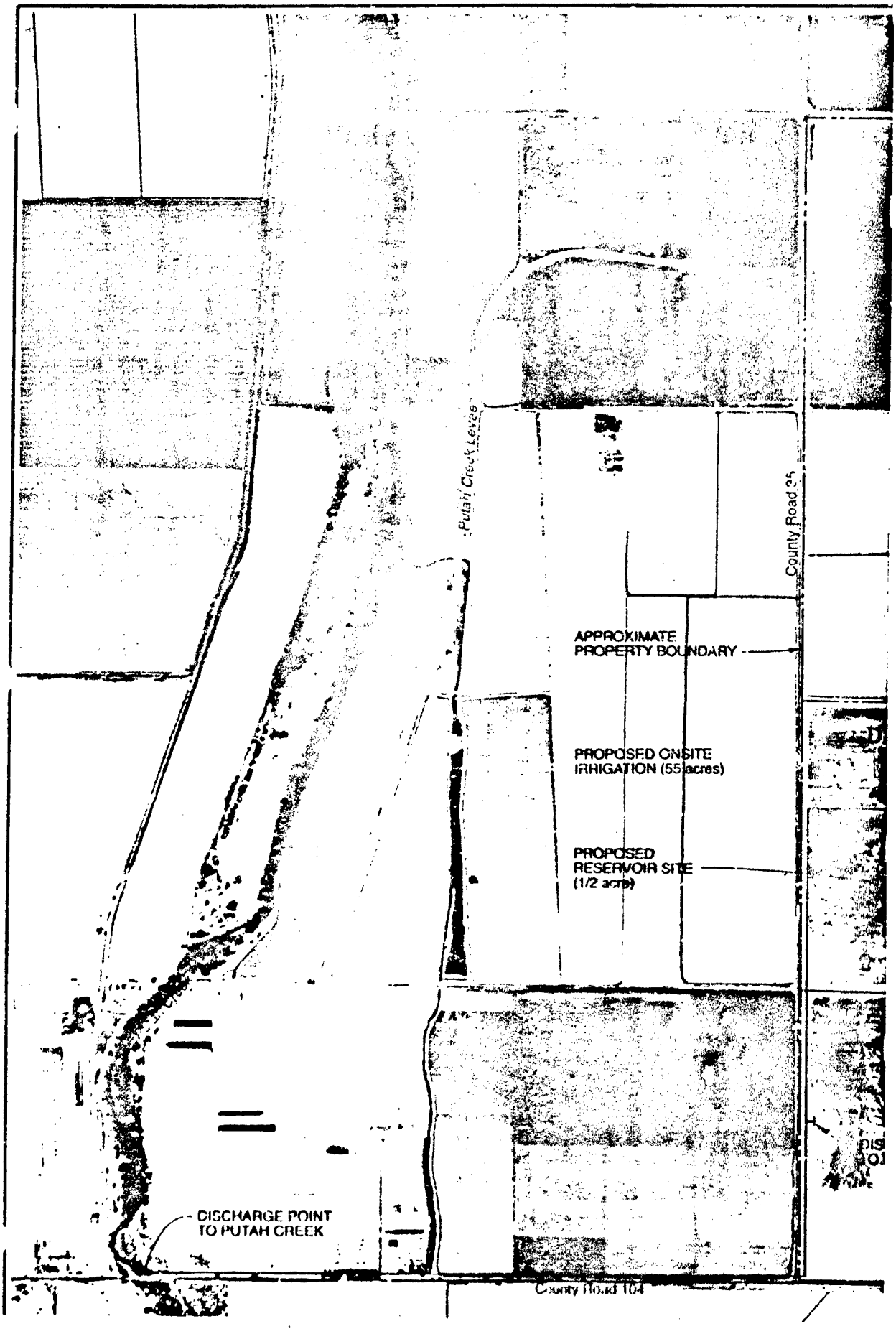
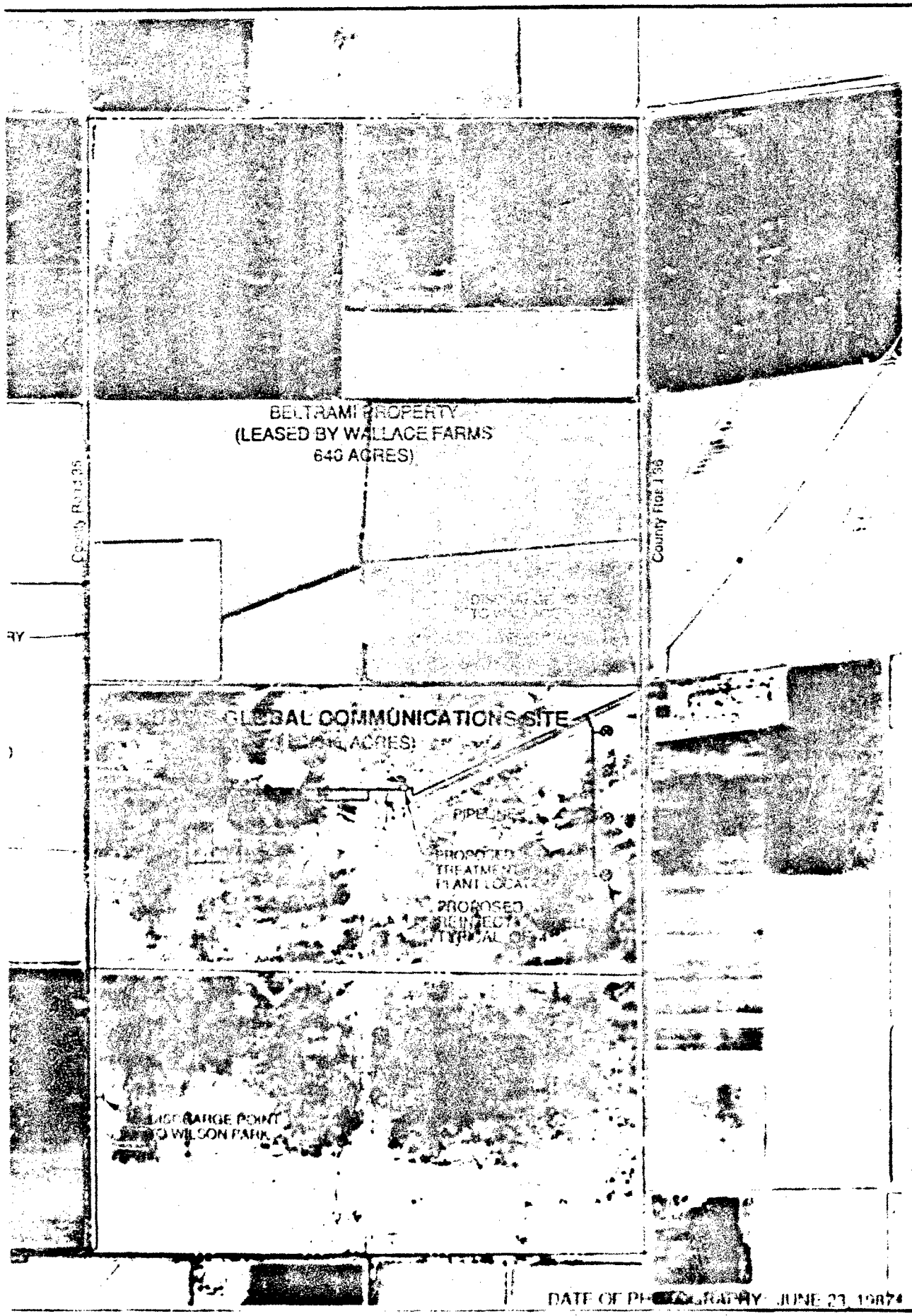


FIGURE M(b)-1
WILSON PARK MASTER PLAN
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE


Putah Creek Levee
County Road 35
APPROXIMATE
PROPERTY BOUNDARY
PROPOSED ONSITE
IRRIGATION (55 acres)
PROPOSED
RESERVOIR SITE
(1/2 acre)
DISCHARGE POINT
TO PUTAH CREEK
County Road 104



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DATE OF PHOTOGRAPHY: JUNE 23, 1987

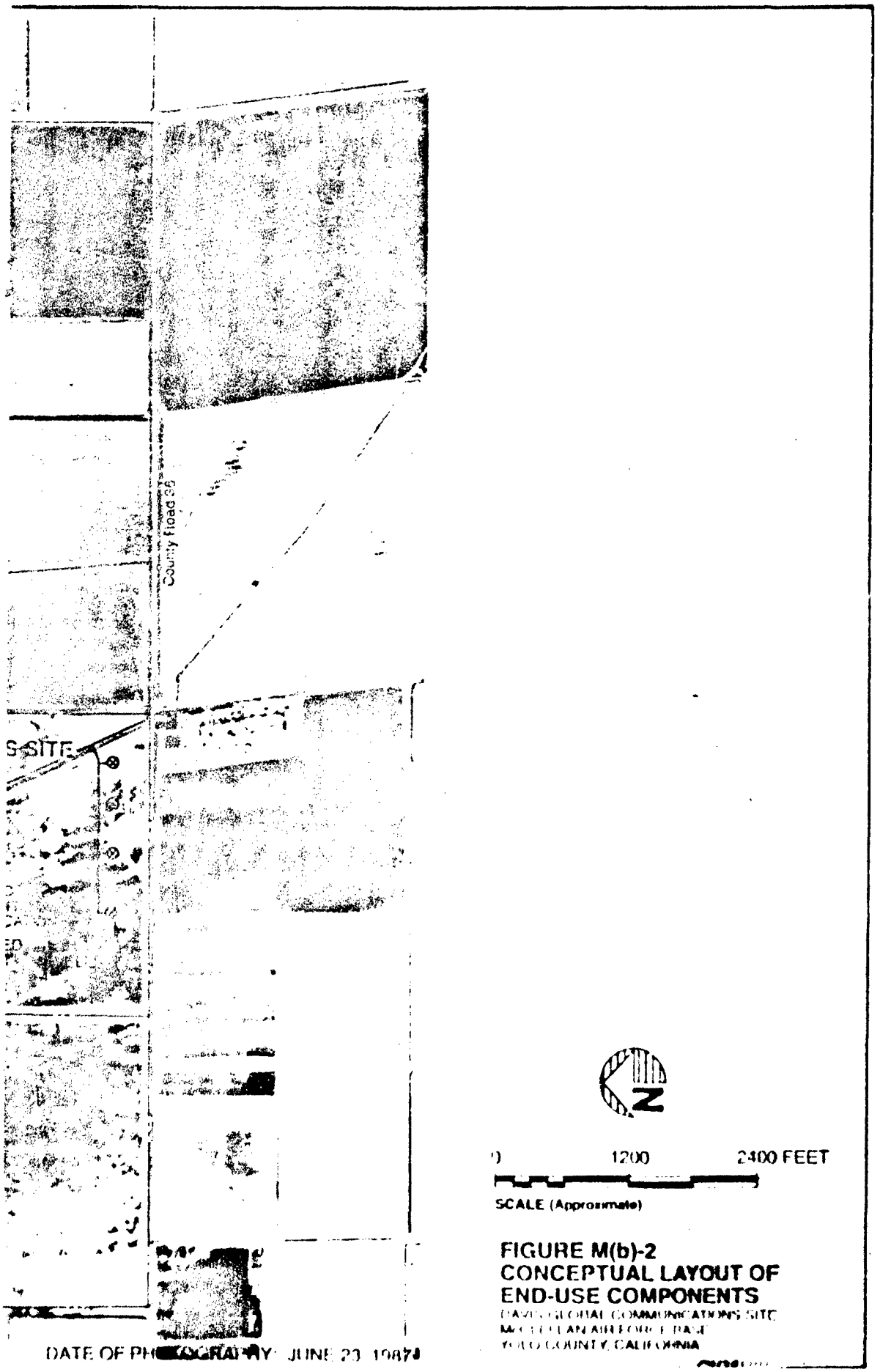


FIGURE M(b)-2
CONCEPTUAL LAYOUT OF END-USE COMPONENTS
DAVIS GLOBAL COMMUNICATIONS SITE
MCCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

The level of management required by McClellan AFB to provide an irrigation supply for Wilson Park would include regular maintenance of the onsite pump station. In addition, periodic meetings with Yolo County personnel may be appropriate.

Option 2—Wallace Farms Irrigation

Site Description

The area surrounding the Davis Site is predominantly used for irrigated agriculture. Typical crops include alfalfa, corn, sugar beets, and tomatoes. Three farmers with a total of approximately 1,200 acres of land adjacent to the Davis Site were contacted to determine their interest in using treated groundwater for surface irrigation. Currently, all three farmers obtain their irrigation water by pumping groundwater.

All of the farmers are interested in receiving treated groundwater if it could be delivered to the headworks of their respective irrigation systems. The proposed treated groundwater flow ranges (380 to 820 gpm) are small in comparison with their normal irrigation flow requirement (2,000 to 6,400 gpm). The farmers indicated that the treated groundwater should be delivered at a uniform flow rate so they could regulate their pumping to provide the appropriate total flow to their fields.

The Beltrami property, currently leased by Wallace Farms, was considered to be the best option among the three farms. This parcel is adjacent to the eastern border of the Davis Site and consists of nine fields, covering 640 acres. The farm has a pump station at the southwest corner of the property where groundwater is discharged into onfarm canals for gravity distribution to the nine fields. Typical crops grown include alfalfa, sugar beets, tomatoes, corn, with some safflower and grain.

Water Usage

The average water usage by Wallace Farms is approximately 1,280 acre-feet during the 7-month growing season. The water usage assumes that the current crop rotation would continue for the future. During the 1992 growing season, approximately 40 percent of the land was used to grow alfalfa, with the remaining 60 percent in annual crops of sugar beets, tomatoes, and corn.

As stated earlier, the flow of treated groundwater will only serve a percentage of the water required by Wallace Farms, as indicated below:

- Scenario No. 1—Would provide approximately 28 percent of the water required by Wallace Farms.
- Scenario No. 2—Would provide approximately 60 percent of the water required by Wallace Farms.

From the farmers' perspective, the treated groundwater would be a supplemental supply to their existing groundwater supply.

Water Distribution Facilities Required

The facilities required to provide treated groundwater to the southeast corner of Wallace Farms is shown in Table M(b)-3. The facility sizes vary with the associated groundwater pumping scenario. The distribution pump was sized to deliver water at 5 psi. A low delivery pressure was used since the treated groundwater will be discharged into the canal systems headworks for gravity distribution throughout the nine fields. The distribution pipeline was sized to keep water velocities below 5 fps.

Table M(b)-3
Facilities Required for Supplemental Irrigation at Wallace Farms

Facilities		Groundwater Pumping Scenarios	
		No. 1	No. 2
1.	Distribution Pump Station		
	- Design Flow (gpm)	380	820
	- Total Dynamic Head (ft)	87	42
	- Delivery Pressure (psi)	5	5
	- Motor Size (hp)	15	15
2.	Distribution Pipeline		
	- Diameter (in.)	6	10
	- Length (ft)	2,850	2,850
3.	Discharge Structure	1	1

In addition to the facilities listed in Table M(b)-3, the system would require telemetry control from the treatment plant to the discharge point at Wallace Farms. This system would allow Wallace Farms to have control over the flow of water. Figure M(b)-2 provides a conceptual layout of the major facilities required to provide water to the Wallace Farms irrigation site.

Institutional Issues

A Report of Waste Discharge will be required by the RWQCB. The report requires the submittal of the project design information and a location map. Once information is submitted to the RWQCB, a permit should be issued within 6 months.

Wallace Farms is willing to take the treated groundwater as soon as it is available. A user agreement should be developed and signed for the understanding and protection of both McClellan AFB and Wallace Farms as was described previously under Option 1.

The level of management required by McClellan AFB for providing an irrigation supply to Wallace Farms would be to perform regular maintenance on the onsite pump station.

Option 3—Surface-Water Discharge to Putah Creek

Site Description

Putah Creek is an intermittent stream approximately 1 mile north of the Davis Site. As shown in Figure M(b)-2, the creek is contained by levees on both sides. The flood plain contained within the levees is approximately 2,000 feet wide, with a portion of the flood plain under agricultural production. The stream channel is thick with brush and additional riparian vegetation and trees. Although this option has the lowest priority as a beneficial use of water, adding water to the creek may provide some riparian habitat enhancement.

Water Usage

Putah Creek should be able to accommodate the relatively small flows from the groundwater treatment facility. The treated groundwater quality would have to comply with California's Inland Surface-Water Plan.

Water Distribution Facilities Required

The facilities required to convey treated groundwater to an outfall at Putah Creek along County Roads 35 and 104 are shown in Table M(b)-4. The facility sizes vary with the associated groundwater pumping scenario. The distribution pump was sized to deliver water at 5 psi. A low delivery pressure was used since the treated groundwater will be discharged directly into Putah Creek. The distribution pipeline was sized to keep water velocities below 5 fps. Figure M(b)-2 provides a conceptual layout of the major facilities required to convey water to Putah Creek.

Institutional Issues

There are several permits that will be required for this option. A National Pollutant Discharge Elimination System (NPDES) permit will be required for direct discharge into Putah Creek. This permit is issued by the Central Valley RWQCB in Sacramento. The permit requires the submittal of a Report of Waste Discharge, additional project design information, a location map, systems operation, and expected effluent concentrations. Once information is submitted to the RWQCB, a permit should be issued within 6 months.

Table M(b)-4 Facilities Required at Putah Creek			
		Groundwater Pumping Scenarios	
	Facilities	No. 1	No. 2
1.	Distribution Pump Station		
	- Design Flow (gpm)	380	820
	- Total Dynamic Head (ft)	77	103
	- Delivery Pressure (psi)	5	5
	- Motor Size (hp)	15	30
2.	Distribution Pipeline		
	- Diameter (in.)	8	10
	- Length (ft)	13,100	13,100
3.	Discharge Structure	1	1

To construct an outfall into Putah Creek, an Army Corp of Engineers (COE) permit NW-12 Utility Line Backfill and Bedding will be required. This permit is issued by the COE Sacramento District Office in Sacramento. The permit requires the submittal of the project plans. Once information is submitted to COE, a permit should be issued within 2 to 4 weeks.

A California Fish and Game Stream Bed Alteration Agreement will also be required. This permit is issued by the California Fish and Game Region 2 office in Rancho Cordova. The permit requires the submittal of the project plans and a site visit with the Yolo County game warden. Once information is submitted to California Fish and Game, a permit should be issued within 4 weeks.

The level of management required by McClellan AFB for discharging treated water to Putah Creek would be to perform periodic water quality analysis as required by the NPDES permit, other permit requirements unforeseen at this time, and regular maintenance of the onsite pump station.

Option 4—Groundwater Reinjection

Site Description

The approximate locations of the four groundwater reinjection wells are shown in Figure M(b)-3. Each reinjection well should have the capacity to reinject up to 250 gpm into the D and E aquifers. The reinjection wells are located approximately 1,800 feet south of the proposed treatment plant. The reinjection well locations are assumed to be in an area in which the vadose zone and saturated zone are not contaminated.

Reinjection Limitations

Physical. The amount of water that can be reinjected to the B, C, D, and E aquifers is limited by the aquifer transmissivity and by the maximum height of acceptable groundwater mounding. Preliminary results presented in Appendix J suggest that as much as 250 gpm may be reinjected into the E aquifer and water levels within the target area will increase less than 2 feet. If excessive pressures are applied to the aquifer formation during reinjection, the physical stability of the reinjection well may be compromised.

Geochemical. As discussed in Appendix J, the potential problem constituents for reinjection are calcium, magnesium, silica, manganese, and iron. Treatment processes tend to elevate the pH of the extracted groundwater, causing precipitation of metals (iron and manganese) and calcium carbonate. A provision in the treatment process should be made to accumulate any precipitates on a filter before reinjection into the native groundwater. If the pH of the reinjected water is stabilized at-or near background levels (assumed to be 7.3 to 8.0); reaction between the reinjected and in situ groundwater and between the reinjected groundwater and the aquifer mineralogy should be minimized. The major ion chemistry of the in situ groundwater and the treated water should be characterized before any reinjection occurs. Once the ion chemistry is known, the precipitation reactions should be checked using a thermodynamic equilibrium model. The equilibrium modeling will identify compounds that have a tendency to precipitate under the proposed treatment processes and conditions. Recommendations can then be made to identify corrective measures for potential problem precipitates.

Water Distribution Facilities Required

Table M(b)-5 lists the facilities required for reinjection. Approximately 3,600 feet of pipeline will be required to convey the water from the treatment plant to the reinjection wells. Four reinjection wells are proposed so that at least one can serve as a backup to allow reinjection to continue during well maintenance periods. Pumps may need to be installed in the reinjection wells to allow periodic backflushing. A pump at the treatment plant will be required to deliver treated groundwater to the reinjection wells at approximately 5 psi.

In addition to the facilities listed in Table M(b)-5, the system would require a telemetry control system linking the treatment plant pump to the reinjection wells. The telemetry is required for automating operations. Figure M(b)-3 provides a conceptual layout of the major facilities required for the reinjection system. Figure M(b)-4 provides a reinjection well construction schematic. The actual depths of the screened interval will be determined in the field.

Table M(b)-5 Facilities Required for Groundwater Reinjection		
	Groundwater Pumping Scenarios	
Facilities	No. 1	No. 2
1. Distribution Pump Station		
- Design Flow (gpm)	380	820
- Total Dynamic Head (ft)	110	50
- Delivery Pressure (psi)	5	5
- Motor Size (hp)	15	15
2. Distribution Pipeline		
- Diameter (in.)	6	10
- Length (ft)	3,600	3,600
3. Reinjection Wells		
- No. of Wells	3	4
- Casing Diameter (in.)	12	12
- Total Depth (ft)	280	280

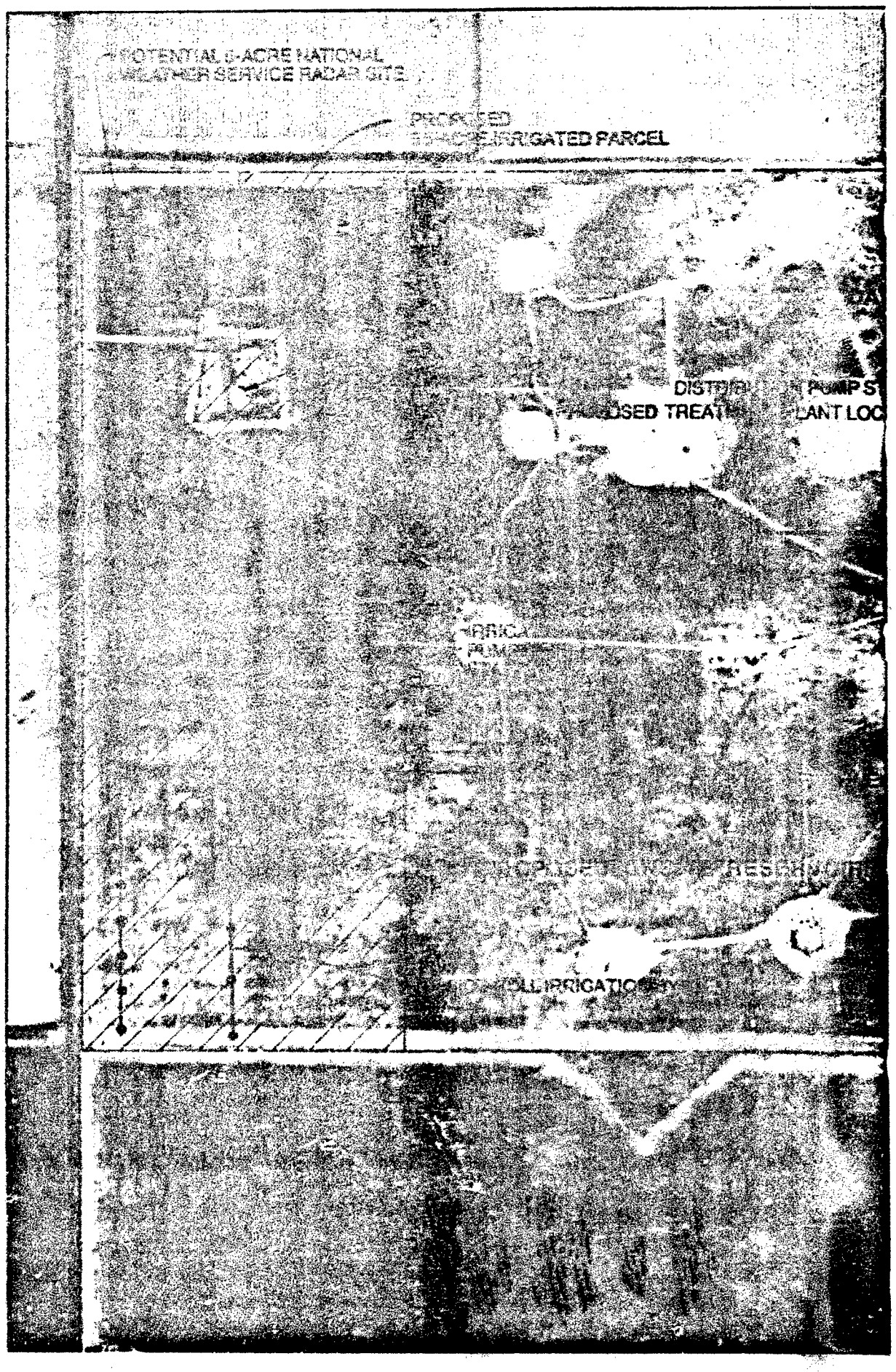
Institutional Issues

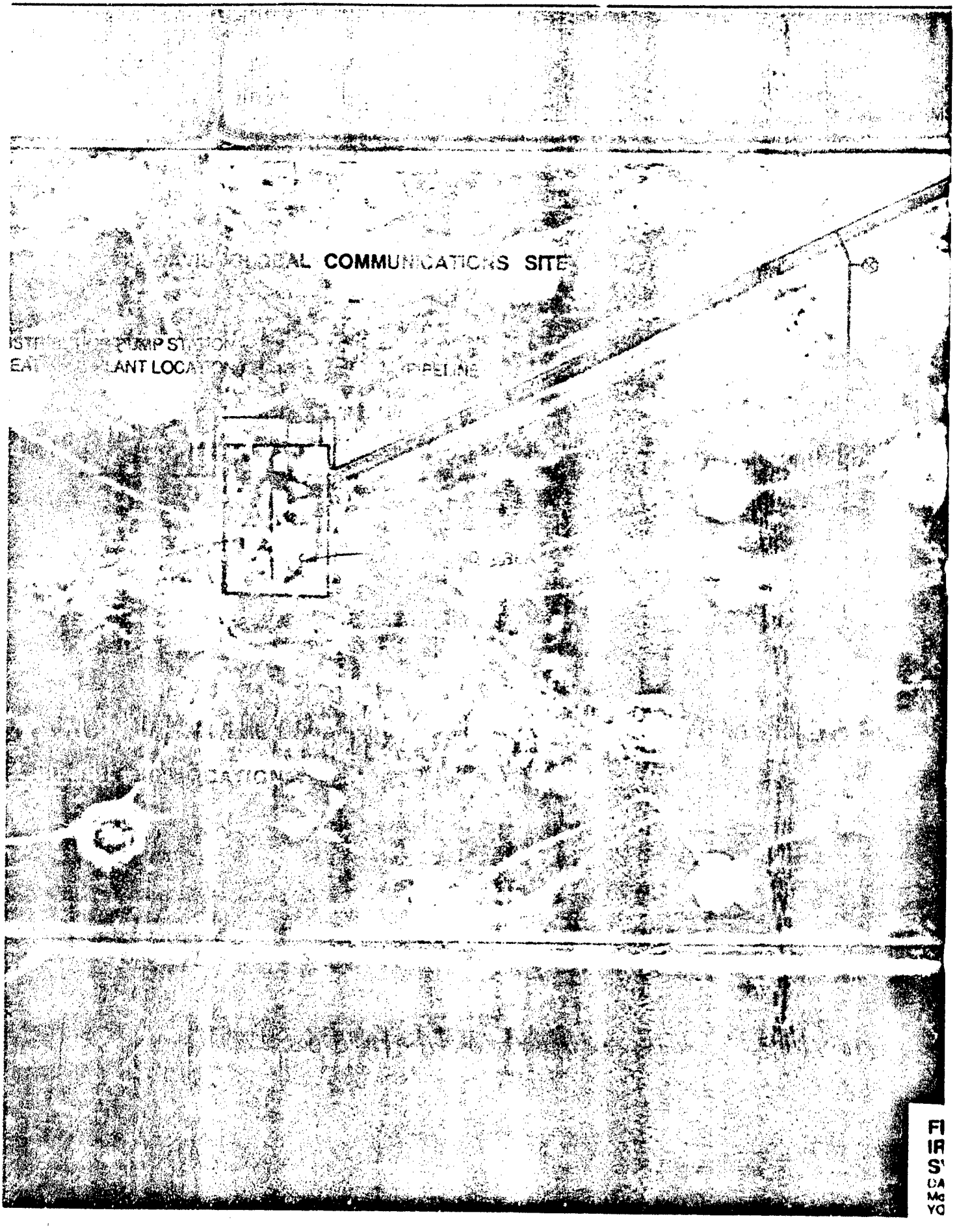
A Report of Waste Discharge will be required by the RWQCB for operating the end-use system. The Environmental Protection Agency (EPA) may require a Class V permit for groundwater reinjection. However, it is expected that EPA will not require the permit and will designate the RWQCB as the permitting agency.

The RWQCB and the Department of Toxic Substances Control (DTSC) recommend that for groundwater reinjection, the effluent concentration of inorganic constituents be similar to background concentrations. A review of available water quality data was performed and is summarized in Table M(b)-6. On the basis of the limited data, the quality of the B aquifer is apparently similar to that of the C aquifer. As additional data become available, it will be incorporated into the subsequent drafts of this report.

The limited data show that the concentration of manganese is above the maximum contaminant level (MCL) in the B and C aquifers. A previous groundwater quality study observed that wells within about 10 miles of the Sacramento River had manganese concentrations ranging from 0.02 to 0.18 mg/l (Evenson, 1985). The secondary MCL for manganese is 0.05 mg/l. Manganese concentrations in the Davis Site B and C aquifers average 0.13 mg/l, with 8 of the 17 wells exceeding the secondary MCL.

McClellan AFB would be responsible for the following operation activities: operating and maintaining the conveyance line and reinjection wells, monitoring water levels and pressures inside the wells, evaluating data, and coordinating with an offsite irrigation operator (if necessary). The operation of the reinjection system may require decisions and data evaluations throughout the year.


POTENTIAL 5-ACRE NATIONAL
WEATHER SERVICE RADAR SITE
PROPOSED
IRRIGATED PARCEL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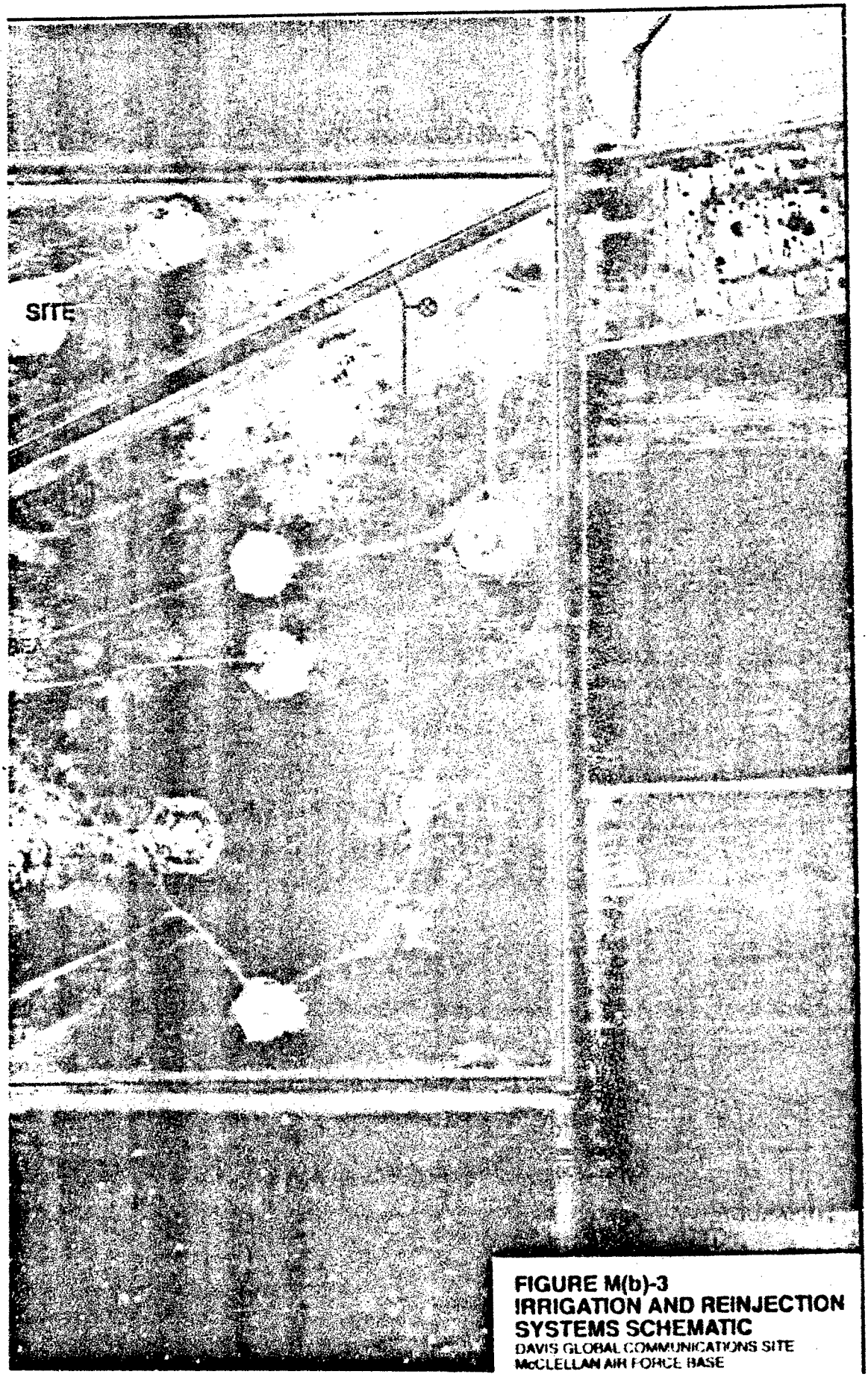
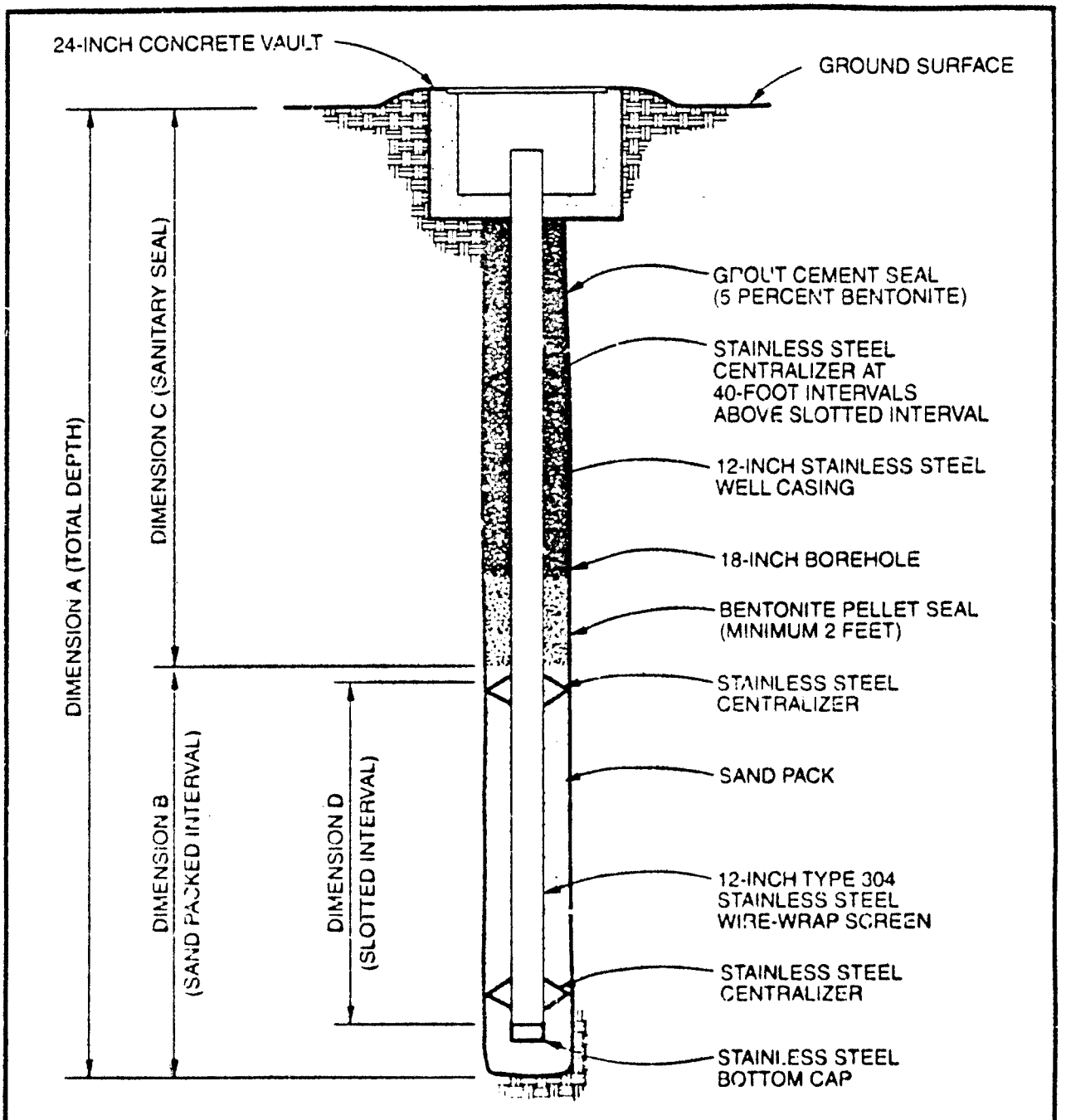


FIGURE M(b)-3
IRRIGATION AND REINJECTION SYSTEMS SCHEMATIC
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE



WELL	DIMENSION A (FEET)	DIMENSION B (FEET)	DIMENSION C (FEET)	DIMENSION D (FEET)
REINJECTION WELLS NO. 1, NO. 2, NO. 3, AND NO. 4	280	50	230	40[a]

NOTE:
[a] Total slotted interval is adjacent to E aquifer

Actual well construction may vary depending on field conditions.

FIGURE M(b)-4
SCHEMATIC OF REINJECTION WELL CONSTRUCTION
DAVIS GLOBAL COMMUNICATIONS SITE
MCCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

PDD1412 264

Table M(b)-6
Summary of Metals Concentrations in B, C, and D Aquifers, July 1992[a] and E Aquifer, July 1993

Analyte	B Aquifer Average Concentration (mg/l)[b]	C Aquifer Average Concentration (mg/l)[c]	D Aquifer Average Concentration (mg/l)[d]	E Aquifer Average Concentration (mg/l)[e]
Aluminum	--	--	ND	--
Antimony	0.11	0.058	0.08	--
Arsenic	--	--	ND	--
Barium	0.13	0.11	0.10	0.13
Beryllium	--	--	--	--
Cadmium	0.0058	--	--	--
Calcium	31	32	27	32
Chromium	0.023	0.012	0.011	0.012
Cobalt	0.008	0.028	--	--
Copper	--	--	0.026	--
Iron	0.063	6.3	--	0.19
Lead	--	0.058	--	--
Magnesium	102	94	69	68
Manganese	0.13	0.14	0.0024	0.009
Molybdenum	0.012	0.012	0.013	--
Nickel	0.23	3.7	0.42	--
Potassium	--	12.7	3.7	--
Selenium	--	0.079	0.10	0.0032
Silver	--	0.36	--	--
Sodium	126	109	80	58
Thallium	--	--	--	--
Vanadium	0.012	0.013	0.014	0.018
Zinc	0.04	0.033	0.047	0.10

[a]Radian, 1992.
[b]Averages based on data from 12 B aquifer wells.
[c]Averages based on data from seven C aquifer wells.
[d]Averages based on data from seven D aquifer wells.
[e]Based on April 1993 data from Well MWE-3.
ND = Not Detected.

Option 5—Onsite Irrigation

Site Description

The proposed site for irrigation at the Davis Site consists of approximately 55 acres on the north end of the site parallel to County Road 35, as shown in Figure M(b)-3. The buildings shown in the northeast corner of Figure M(b)-3, formerly known as the north repair area, have been removed since the photograph was taken. Currently, this 55-acre parcel is the only large section of land on the Davis Site that is not occupied by buildings or communication antennas.

Information from the Yolo County Soil Survey (USDA-SCS, 1972) indicates that the 55-acre parcel consists of Brentwood silty clay loam and Marvin silty clay loam soils; both soils are classified as agricultural soils. These soils are found on the irrigated farmland adjacent to the Davis Site.

From 1968 through 1983, McClellan AFB had leased the Davis Site to private ranchers for growing forage crops and grazing sheep. Sheep were allowed to graze from November 1 through June 30. The full extent of using the Davis Site for agricultural purposes is presented in *Grazing and Cropland Management Plan for Davis Communications Site, California* (Cox and Schulze, 1984). Apparently, the lease was not renewed because of excessive restrictions placed on the rancher.

For this end-use option, it is recommended that the 55 acres be planted in alfalfa and grain sorghum crop rotation, irrigated with the treated groundwater through a sprinkler system, and harvested for hay. No livestock grazing should be permitted because of possible soil compaction during irrigation.

Water Usage

The average water usage during a 7-month growing season for alfalfa or grain sorghum on 55 acres would be approximately 260 acre-feet assuming 70 percent irrigation efficiency. The water usage assumes a repeated crop rotation that would include growing alfalfa for 5 years, followed by 1 year of grain sorghum.

The water usage of 260 acre-feet means that an additional end-use option is required to meet the treated groundwater supply for Scenarios No. 1 and No. 2. The variances with each scenario are explained in the following paragraphs:

- **Scenario No. 1**—Approximately 250 acre-feet of water would be discharged to another end-use option from November 1 through March 31. The onsite irrigation system would apply 260 acre-feet during the 7-month growing season. The remaining 100 acre-feet would be discharged to another end-use option.

- **Scenario No. 2**—Approximately 550 acre-feet of water would be discharged to another end-use option from November 1 through March 31. The onsite irrigation system would apply 260 acre-feet during the summertime, with the remaining 510 acre-feet discharged to another end-use option.

Storage and Water Distribution Facilities Required

Three irrigation systems were evaluated: (1) surface irrigation as practiced by adjacent farmers, (2) solid set sprinkler irrigation, and (3) side-roll sprinkler irrigation. Surface irrigation was ruled out because of the relatively low flow of water available in Scenario No. 1 and the extensive land grading and preparation required. Solid set sprinkler irrigation was ruled out because of the management problems associated with harvesting alfalfa between 30-inch-tall sprinkler risers on a 40-foot by 40-foot spacing and the high capital cost. A side-roll irrigation system was chosen because of its current use by local farmers, low management requirements, and low capital costs.

Each side-roll irrigation system would consist of 64-inch-diameter wheels mounted on 5-inch-diameter aluminum lateral pipes, with the pipe serving as the axle of the wheel. Rigid couplers permit the entire 1,280-foot-long lateral to be rolled forward by applying power at the center while the pipe remains in a nearly straight line. The sprinkler spacing and pipe lengths are 40 feet. The wheels are placed in the center of each length of pipe. Thus, a standard 1,280-foot lateral contains 32 pipe lengths, 32 sprinklers, and 36 wheels because 4 wheels are required for the drive unit. The drive unit contains a gasoline engine and a transmission with a reverse gear (Jensen, 1983).

The facilities required for the onsite irrigation system are shown in Table M(b)-7. The facility sizes do not vary with the associated groundwater pumping scenario since the onsite irrigation system can only accommodate 250 gpm. Approximately 1,600 feet of pipeline will be required to convey water from the treatment plant to the reservoir, as shown in Figure M(b)-3. A pump at the treatment plant will deliver water to the reservoir at approximately 5 psi. The reservoir was sized to store approximately 3 days of summertime flow (380 gpm). The 3-day storage margin allows for potential shutdown due to maintenance requirements of the treatment plant, and to balance out the daily flows between the treatment plant and the irrigation system.

The distribution pipeline was sized to keep water velocities below 5 fps. The irrigation pump was sized to deliver water from the reservoir to the irrigation system at 60 psi. The side-roll irrigation system was sized to minimize ponding (i.e., to apply water at 0.2 inch per hour, approximately the soil infiltration rate presented in Appendix C(a)) and to meet the water requirements for the alfalfa. Because of the low application rate, four side-rolls are required. Three side-rolls would deliver approximately 160 gpm each (5 gpm/sprinkler), and the fourth side-roll would deliver approximately 100 gpm.

In addition to the facilities listed in Table M(b)-7, the system would require a telemetry control system linking the treatment plant pump to the reservoir level. The telemetry is required for automating the pump operation. It is anticipated that the treatment plant pump would operate 24 hours per day while the irrigation pump would operate 16 hours per day. Figure M(b)-3 provides a conceptual layout of the major facilities required to provide treated groundwater to the parcel.

Table M(b)-7
Facilities Required for Onsite Irrigation

Facilities	Groundwater Pumping Scenarios	
	No. 1	No. 2
1. Distribution Pump Station		
- Design Flow (gpm)	380	380
- Total Dynamic Head (ft)	76	76
- Delivery Pressure (psi)	5	5
- Motor Size (hp)	15	15
2. Reservoir Conveyance Pipeline		
- Diameter (in.)	6	6
- Length (ft)	1,600	1,600
3. Onsite Reservoir		
- Capacity (ac-ft)	5	5
- Surface Area (ac)	0.5	0.5
- Maximum Water Depth (ft)	10	10
4. Irrigation Pump Station		
- Design Flow (gpm)	580	580
- Total Dynamic Head (ft)	175	175
- Delivery Pressure (psi)	60	60
- Motor Size (hp)	40	40
5. Irrigation Pipeline		
- Diameter (in.)	8	8
- Length (ft)	1,350	1,350
6. Side-Roll Irrigation Systems (4 units)		
- Diameter (in.)	5	5
- Length (ft) ~ 3 units	1,280	1,280
- Length (ft) ~ 1 unit	800	800

Institutional Issues

A Report of Waste Discharge will be required by the RWQCB. The report will require submittal of the project design information and a location map. Once the information is submitted to the RWQCB, a permit should be issued within 6 months.

A lease should be developed and signed for the understanding and protection of both McClellan AFB and the farmer. The lease should include the following basic provisions:

- The length or term of the agreement
- Conditions for termination for both parties
- Treated water quality, quantity, and onsite storage capacity
- Methods of treated water delivery and irrigation/disposal requirements
- Mutual liability considerations
- Right of entry
- Other general considerations

The level of management required by McClellan AFB to provide an onsite irrigation supply for the farmer would include regular maintenance of the reservoir conveyance pipeline, the reservoir, irrigation pump, site access, and fencing associated with the 55-acre parcel. The maintenance, management and power for the irrigation pump, irrigation pipeline, the side-roll irrigation system, the 55-acre parcel, and the crop would be the responsibility of the lessee. This management arrangement follows typical agricultural lease arrangements in the area.

Estimated Capital Costs

An order-of-magnitude cost estimate was prepared for the groundwater extraction system (presented in Appendix J) and each of the end-use components in accordance with the guidelines of the American Association of Cost Engineers. This is an approximate estimate made without detailed engineering data. The estimate was founded on cost curves and preliminary estimated quantities of major facility components. It is normally expected that an estimate of this type would be accurate within +50 percent or -30 percent.

The cost estimates shown have been prepared for guidance in project evaluation and implementation from the information available at the time of the estimate. The final costs of the project and resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, and other variable factors. As a result, the final project costs will vary from the estimates presented here. Because of these factors, project feasibility, benefit cost ratios, risks, and funding needs must be carefully reviewed prior to making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

Pipeline costs were developed assuming polyvinyl chloride (PVC) pipe with an installed cost of $4.50 per diameter-inch per foot. Reservoir costs were developed assuming an unlined earth embankment reservoir to be constructed with onsite excavated materials for $7.50 per cubic yard. The side-roll irrigation system costs were developed with an installed cost of $10,000 per unit, which includes 1,280 feet of 5-inch aluminum lateral, 64-inch wheels, 30 Rainbird 30WSH sprinklers, and a driving unit. The pump stations were developed using $1,500 per hp including any structures and controls. Telemetry and discharge structures were a lump sum estimate calculated from previous work experience costs. Extraction, monitoring, and reinjection well costs were also calculated from previous work experience costs.

The capital costs include several allowances and contingencies. A 15 percent construction allowance was included to cover materials, labor, and equipment necessary for construction items that could not be detailed at this level of study. A bid contingency of 15 percent was included to provide for unforeseeable costs related to construction activities. A scope contingency of 10 to 25 percent was included to address uncertainties in the scope of some activities (e.g., the total number of reinjection wells). In addition, allowances were included for permitting and legal (5 percent), services during construction (10 percent), and engineering design costs (10 percent).

The estimated capital cost for the extraction system described in Appendix J is approximately $95,000 for groundwater pumping Scenario No. 1 and approximately $342,000 for groundwater pumping Scenario No. 2 as presented in Table M(b)-8.

Table M(b)-8
Estimated Capital Costs
for the Extraction System

Facilities	Groundwater Pumping Scenarios ($)	
	No. 1	No. 2
Extraction Wells	Existing	100,000
Submersible Pumps	Existing	5,000
Conveyance Pipeline	28,000	42,000
Monitoring Wells	Existing	8,000
Telemetry	20,000	20,000
Subtotal	**48,000**	**175,000**
Construction Allowance (15 percent)	7,000	26,000
Bid Contingency (15 percent)	7,000	26,000
Scope Contingency (25 percent)	12,000	44,000
Total Construction Cost	**74,000**	**271,000**
Permitting and Legal (5 percent)	4,000	13,000
Services during Construction (10 percent)	8,000	27,000
Total Implementation Cost	**86,000**	**311,000**
Engineer Design (10 percent)	8,000	31,000
Total Capital Cost	**95,000**	**342,000**

The estimated capital costs for the five end-use components for two flow-rate scenarios are presented in Table M(b)-9. The estimated capital costs for the preferred end-use components, depending on the groundwater pumping scenario, vary between $212,000 and $304,000 for the Wallace Farm irrigation system and between $540,000 and $750,000 for the groundwater reinjection system. It should be noted that the pipeline sizes in Scenario No. 2 can safely accommodate flows of up to 1,000 gpm to account for possible future expansion of the cleanup efforts.

Table M(b)-9
Estimated Capital Costs for End-Use Options

End-Use Option	Facilities	Capital Cost Per Groundwater Pumping Scenario ($)	
		No. 1	No. 2
Wilson Park	Distribution Pipeline	162,000	--
	Pump Station	38,000	--
	Telemetry	300,000	--
	Subtotal	**500,000**	**--**
	Construction Allowance (15 Percent)	35,000	--
	Bid Contingency (15 Percent)	35,000	--
	Scope Contingency (10 Percent)	23,000	--
	Total Construction Cost	**323,000**	**--**
	Permitting and Legal (5 Percent)	16,000	--
	Services During Construction (10 Percent)	32,000	--
	Total Implementation Cost	**371,000**	**--**
	Engineering Design (10 Percent)	37,000	--
	Total Capital Cost	**408,000**	**--**
Wallace Farms	Distribution Pipeline	77,000	128,000
	Pump Station	23,000	23,000
	Telemetry	10,000	10,000
	Discharge Structure	10,000	10,000
	Subtotal	**120,000**	**171,000**
	Construction Allowance (15 Percent)	18,000	26,000
	Bid Contingency (15 Percent)	18,000	26,000
	Scope Contingency (10 Percent)	12,000	17,000
	Total Construction Cost	**168,000**	**240,000**
	Permitting and Legal (5 Percent)	8,000	12,000
	Services During Construction (10 Percent)	17,000	24,000
	Total Implementation Cost	**193,000**	**276,000**

Table M(b)-9
Estimated Capital Costs for End-Use Options

End-Use Option	Facilities	Capital Cost Per Groundwater Pumping Scenario ($)	
		No. 1	No. 2
Wallace Farms (cont.)	Engineering Design (10 Percent)	19,000	28,000
	Total Capital Cost	**212,000**	**304,000**
Putah Creek	Distribution Pipeline	472,000	590,000
	Pump Station	23,000	45,000
	Discharge Structure	10,000	10,000
	Subtotal	**505,000**	**645,000**
	Construction Allowance (15 Percent)	75,000	97,000
	Bid Contingency (15 Percent)	75,000	97,000
	Scope Contingency (10 Percent)	50,000	64,000
	Total Construction Cost	**705,000**	**903,000**
	Permitting and Legal (5 Percent)	35,000	45,000
	Services During Construction (10 Percent)	70,000	90,000
	Total Implementation Cost	**810,000**	**1,038,000**
	Engineering Design (10 Percent)	81,000	104,000
	Total Capital Cost	**891,000**	**1,142,000**
Groundwater Reinjection	Reinjection Pipeline	97,000	162,000
	Pump Station	23,000	23,000
	Reinjection wells	126,000	168,000
	Telemetry	30,000	30,000
	Subtotal	**276,000**	**383,000**
	Construction Allowance (15 Percent)	41,000	57,000
	Bid Contingency (15 Percent)	41,000	57,000
	Scope Contingency (25 Percent)	69,000	96,000
	Total Construction Cost	**427,000**	**593,000**
	Permitting and Legal (5 Percent)	21,000	30,000
	Services During Construction (10 Percent)	43,000	59,000
	Total Implementation Cost	**491,000**	**682,000**

Table M(b)-9 Estimated Capital Costs for End-Use Options			
End-Use Option	Facilities	Capital Cost Per Groundwater Pumping Scenario ($)	
		No. 1	No. 2
Groundwater Reinjection (cont.)	Engineering Design (10 Percent)	49,000	68,000
	Total Capital Cost	**540,000**	**750,000**
Onsite Irrigation	Distribution Pump Station	23,000	--
	Reservoir Conveyance Pipeline	43,000	--
	Reservoir	75,000	--
	Irrigation Pump Station	60,000	--
	Telemetry	10,000	--
	Irrigation Pipeline	49,000	--
	Side-Roll Irrigation System	40,000	--
	Subtotal	**300,000**	**--**
	Construction Allowance (15 Percent)	45,000	--
	Bid Contingency (15 Percent)	45,000	--
	Scope Contingency (10 Percent)	30,000	--
	Total Construction Cost	**420,000**	**--**
	Permitting and Legal (5 Percent)	21,000	--
	Services During Construction (10 Percent)	42,000	--
	Total Implementation Cost	**483,000**	**--**
	Engineering Design (10 Percent)	48,000	--
	Total Capital Cost	**531,000**	**--**

Estimated Annual Costs

Estimated annual costs were developed for the extraction system, groundwater reinjection, and discharge to Wallace Farms (see Table M(b)-10). Annual costs were developed assuming an 8 percent interest rate, varying facility lives, and a remedial action project life of 30 years. Also included were annual maintenance and repairs, power for the pumps, and groundwater data evaluation for the extraction and reinjection system.

Major facility lives were assumed to be all pipelines 40 years, distribution pump 30 years, all wells 30 years, discharge structures 30 years, and telemetry 30 years. Facility lives were based on Jensen (1983) and project experience. The assumption of a 30 year project life for the remedial action resulted in providing no replacement costs for the major facilities described.

Table M(b)-10
Estimated Annual Costs

System	Item	Annual Cost ($)	
		Groundwater Pumping Scenario No. 1	Groundwater Pumping Scenario No. 2
Groundwater Extraction	Facility maintenance and repair	500	3200
	Data evaluation	35,000	35,000
	Power for extraction pumps	6,200	13,300
	System annualized cost at 8 percent	6,400	23,800
	Total Annual Cost	**48,100**	**75,300**
Groundwater Reinjection	Facility maintenance and repair	41,900	55,200
	Data evaluation	10,000	10,000
	Power for distribution pump	2,000	2,200
	System annualized cost at 8 percent	34,600	46,800
	Total Annual Cost	**88,500**	**114,200**
Discharge to Wallace Farms	Facility maintenance and repair	3,000	3,300
	Power for distribution pump	2,700	2,800
	System annualized cost at 8 percent	14,400	20,300
	Total Annual Cost	**20,100**	**26,400**

Annual maintenance and repairs were based on percentages of the total construction cost as presented in Tables M(b)-8 and M(b)-9. These percentages, based on Jensen (1983) and project experience, were assumed to be: pipelines 0.50 percent, pumps 5 percent, discharge structure 5 percent, extraction wells 1 percent, monitoring wells

5 percent, reinjection wells 20 percent, and telemetry 1 percent. Power for the pumps was based on annual volumes and $0.06/kWh.

Groundwater data evaluation for the extraction system was performed on the basis of measuring water levels in 32 monitoring wells on a monthly basis and preparing quarterly summary reports. Groundwater data evaluation for the reinjection system was performed on the basis of measuring water levels in the four reinjection wells on a monthly basis and preparing quarterly summary reports.

Reinjection System Operation

The reinjection system will be used to reinject approximately 380 gpm or 820 gpm of treated water during wintertime (November 1 through March 31) and as a backup system during the summertime (April 1 through October 31). Each reinjection well is designed to recharge up to 250 gpm into the D and E aquifers. A detailed description of how the reinjection system should be operated is shown in Figure M(b)-5. A brief description of the system control and maintenance, monitoring, and data evaluation activities is provided in the following paragraphs.

System Control and Maintenance

Water will be delivered to the reinjection wells at a pressure of approximately 5 psi. The reinjection system should automatically shut off if the pressure in the well exceeds atmospheric pressure. If atmospheric pressure is exceeded in the well, flow must be diverted to the backup reinjection well or the system will shut down. A data evaluation should be performed to determine if reinjection is limited by physical or geochemical causes. Well rehabilitation or treatment adjustments may be required.

McClellan AFB will be responsible for maintaining the reinjection pipeline. In addition, the reinjection wells should be backflushed periodically to minimize well clogging. Possible constraints that would affect the operation of the reinjection system include:

- Aquifer clogging
- Backflushing requirements
- Water quality requirements
- Bacterial growth in well

Monitoring

The water levels in the reinjection wells should be measured monthly to characterize the magnitude and extent of mounding. The pressure inside the reinjection wells will be measured continuously as discussed above.

Data Evaluation

Data evaluation requirements will be fairly minimal when the reinjection system is operating. Data evaluation will mainly be required if reinjection causes unacceptable mounding or if the well or aquifer becomes clogged. The detailed schematic diagram of the reinjection system operation presented in Figure M(b)-5 shows where data evaluation may be required.

Reinjection and Irrigation Systems Operation

The operation of the reinjection and irrigation systems in conjunction with treatment plant flows will be determined by the seasonal flow variations and the flow capacity of each system. During the summertime, priority will be given to Wallace Farms to handle the treated groundwater flow. The farmer should receive priority over the reinjection system in the summer because of the crop water demand. During the wintertime, priority will be given to the reinjection system to handle the treated groundwater flow.

Figure M(b)-6 presents an operations schematic for both systems. In general, the reinjection system should be operated as described earlier, except that it will act as a backup to the irrigation system in the summertime. The irrigation system should be operated as described below.

Irrigation System Operation

During normal operations, the treatment plant flow of approximately 380 gpm (Scenario No. 1) or 820 gpm (Scenario No. 2) would be sent to Wallace Farms between April 1 and October 31.

During the growing season, there are several cases where the farmer would not be able to apply water through the irrigation system, and the treated groundwater would have to be directed to the reinjection wells. These cases would include when the crop is not planted, when there is excessive soil moisture where water runoff occurs, and when the irrigation system is inoperable. It is anticipated that these cases may occur in the early spring or late fall when precipitation occurs. During normal operation, the water priority should be given to the farmer during the 7-month growing season, with any extra flow going to the reinjection wells.

It is expected that Wallace Farm personnel and the Davis Site personnel will be in contact with each other concerning irrigation startup, treatment plant flow, and handling any problems that may occur.

The quality of the treatment plant effluent will be monitored prior to discharge to the reservoir. Therefore, it is not anticipated that any water quality monitoring would have to be conducted at the irrigation site.

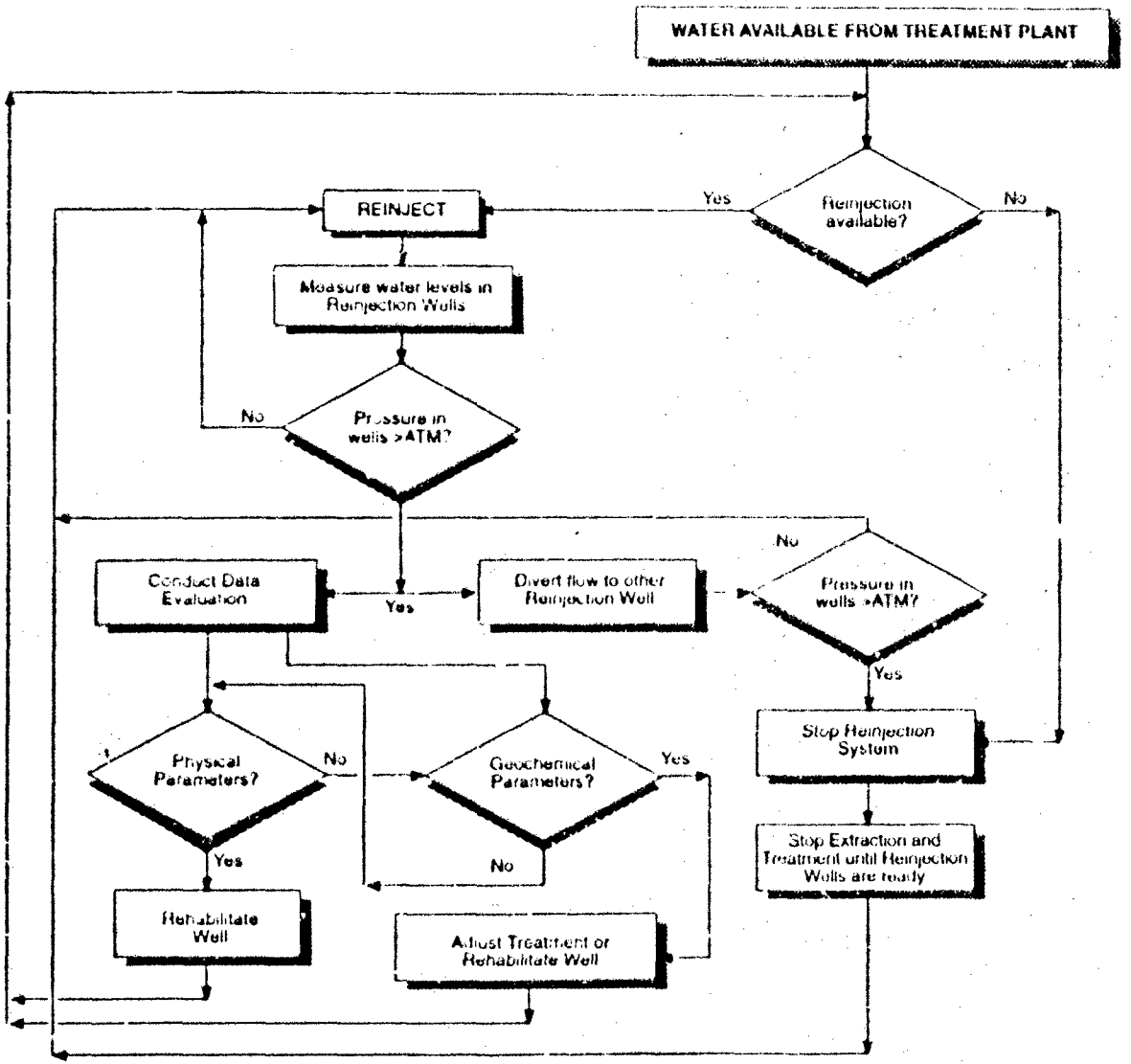


FIGURE M(b)-5
OPERATION SCHEMATIC FOR REINJECTION SYSTEM
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McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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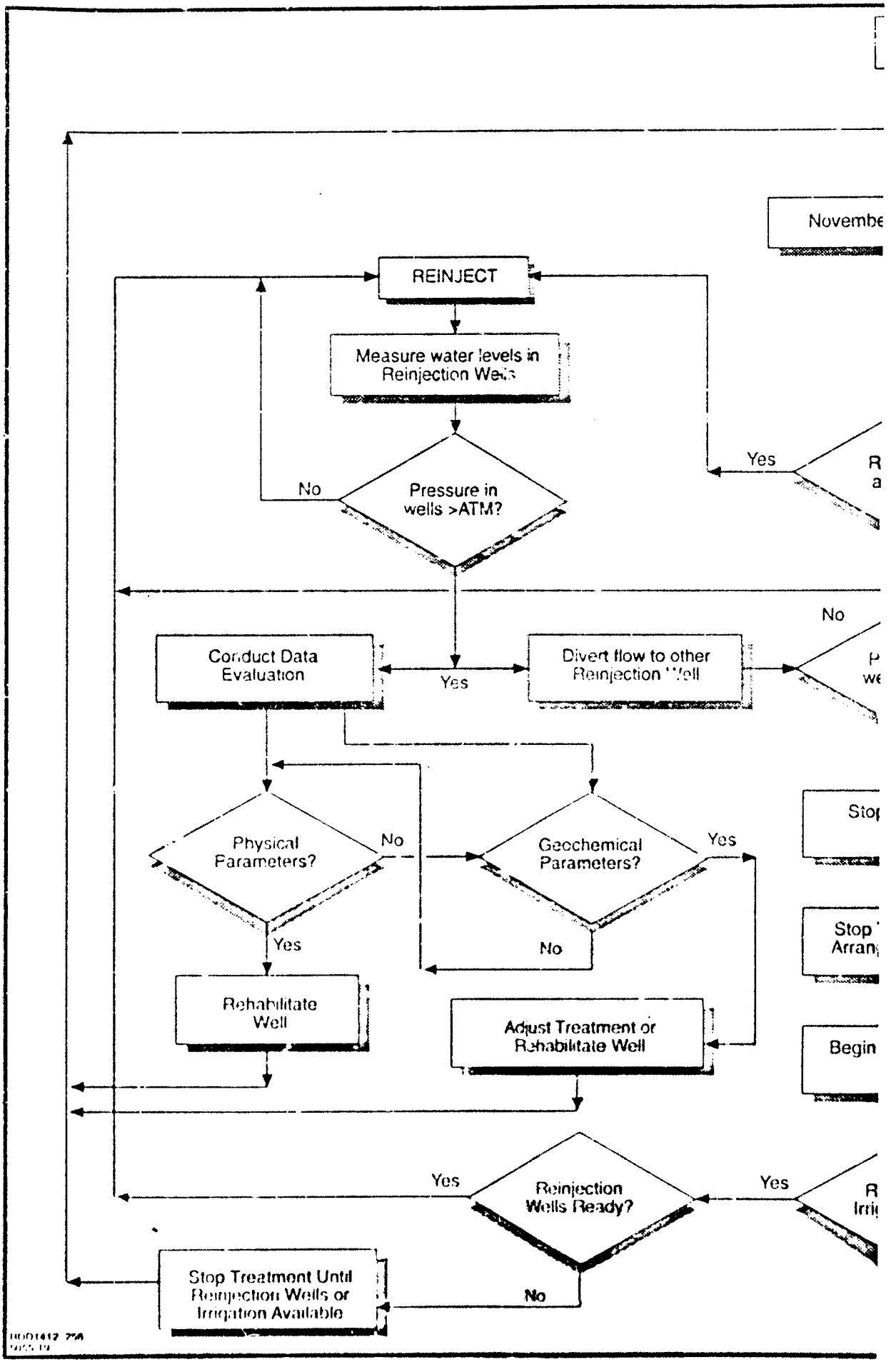
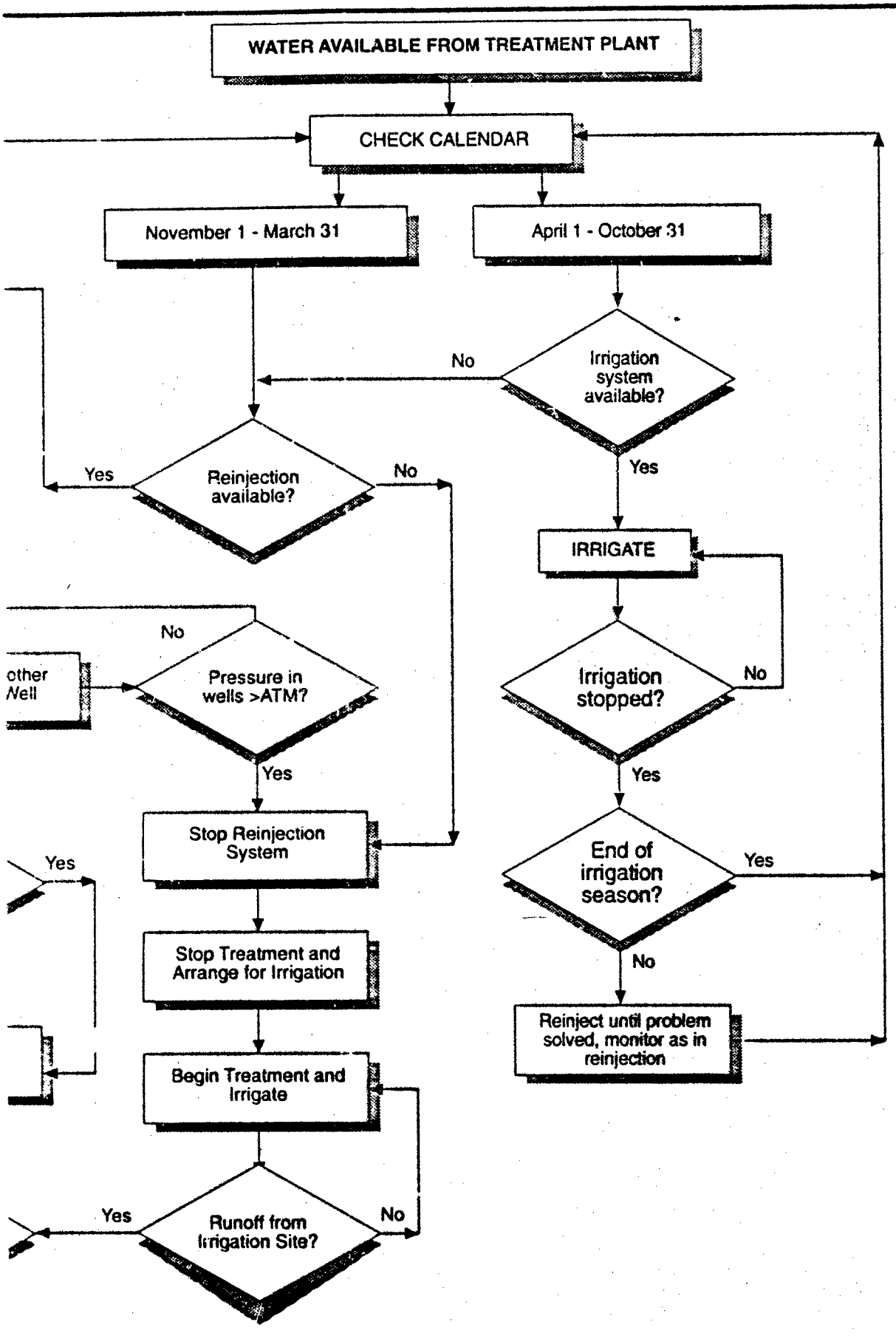

Novembe
REINJECT
Measure water levels in Reinjection Wells
Pressure in wells >ATM?
No
Yes
Conduct Data Evaluation
Yes
Divert flow to other Reinjection Well
No
Physical Parameters?
No
Yes
Geochemical Parameters?
Yes
No
Rehabilitate Well
Adjust Treatment or Rehabilitate Well
Reinjection Wells Ready?
Yes
Yes
No
Stop Treatment Until Reinjection Wells or Irrigation Available



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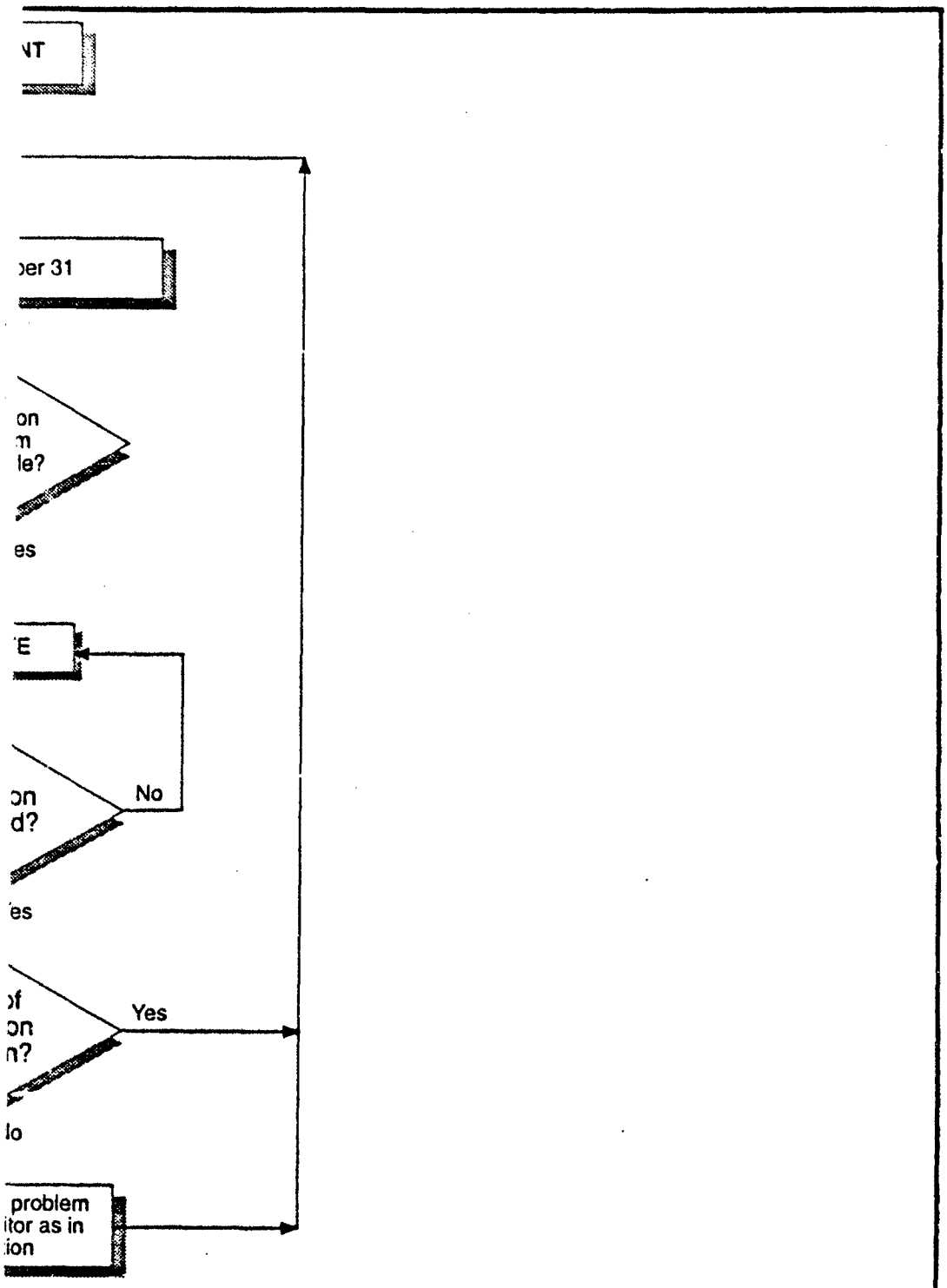

FIGURE M(b)-6
OPERATION SCHEMATIC FOR REINJECTION AND OFFSITE IRRIGATION SYSTEMS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

Conclusions and Recommendations

An end-use system that combines onsite groundwater reinjection and discharge to Wallace Farms appears to be the best system in terms of beneficial use, institutional issues, management, and costs.

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Jensen, Marvin. 1983. *Design and Operation of Farm Irrigation Systems.* American Society of Agricultural Engineers. St. Joseph, Michigan.

Radian. 1992. Davis Site Letter Report. July-September.

U.S. Department of Agriculture–Soil Conservation Service. 1972. *Yolo County Soil Survey.*

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Jim Stefanoff/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Natural Biological Groundwater Attenuation
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.18

Purpose and Scope

The Davis Global Communication Site (Davis Site) groundwater data were reviewed for evaluation of natural biological attenuation of chlorinated aliphatic compounds. This was done because biological attenuation can be a significant process for either chlorinated aliphatic compound destruction or transformation into other, potentially more toxic, compounds. The purpose of this technical memorandum is to present the findings of the evaluation. The objectives of this evaluation are as follows:

- Evaluate if biological attenuation of chlorinated aliphatic compounds is occurring in groundwater at the site
- Identify data needs required for further evaluation of biological attenuation of chlorinated aliphatic compounds

Background

Groundwater Contaminants

The main groundwater contaminants are tetrachloroethene (PCE), trichloroethene (TCE), trans-1,2-dichloroethene (t-1,2-DCE), cis-1,2-dichloroethene (c-1,2-DCE), 1,1-dichloroethene (1,1-DCE), 1,1-dicholorethane (1,1-DCA), and vinyl chloride (VCL). Chloroform, methylene chloride, and toluene have also been detected at low levels (single digit ppb levels or less), but not routinely.

The history of the contamination is not well documented. However, it is thought that spent solvents may have been used along the fence line to control weeds. This area is located north and east of Monitoring Well MW-5. Figure N-1 is a site map that shows well locations, the fence line, and a site schematic.

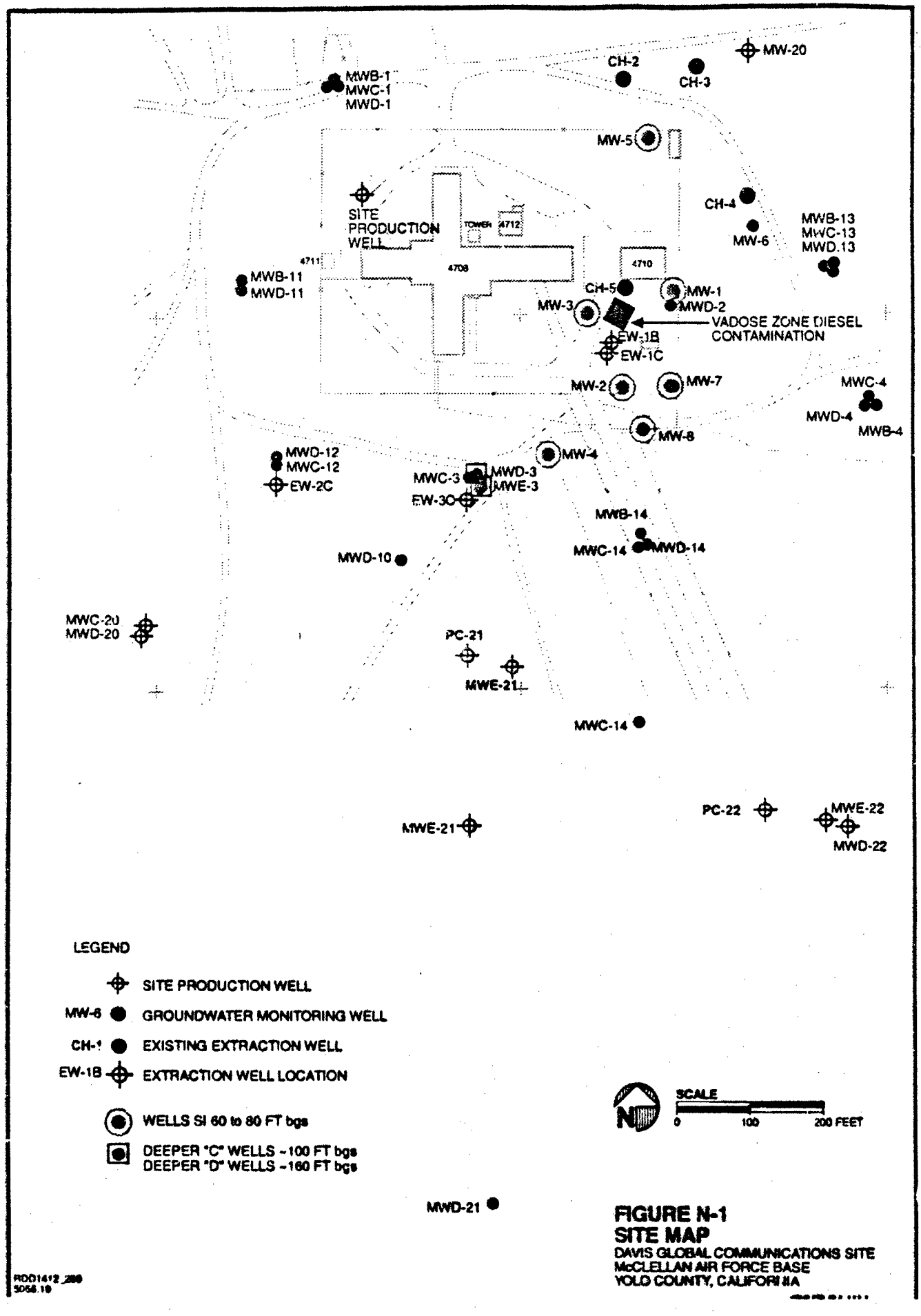

FIGURE N-1
SITE MAP
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Historical contaminant concentrations for MW-1, MW-2, MW-3, MW-5, and MW-7 are shown as Figures N-2 through N-6. Two plots for each well are shown. One plot shows all of the contaminants, and the other plot uses a smaller scale for the ordinate to better present the wells with low concentrations.

Groundwater Movement

The horizontal groundwater movement below the site is thought to be generally towards the south. The groundwater falls and rises about 50 feet once each year because of regional pumping and then recharge. Figure N-7 shows the groundwater elevation measurements collected since 1990 at MW-5.

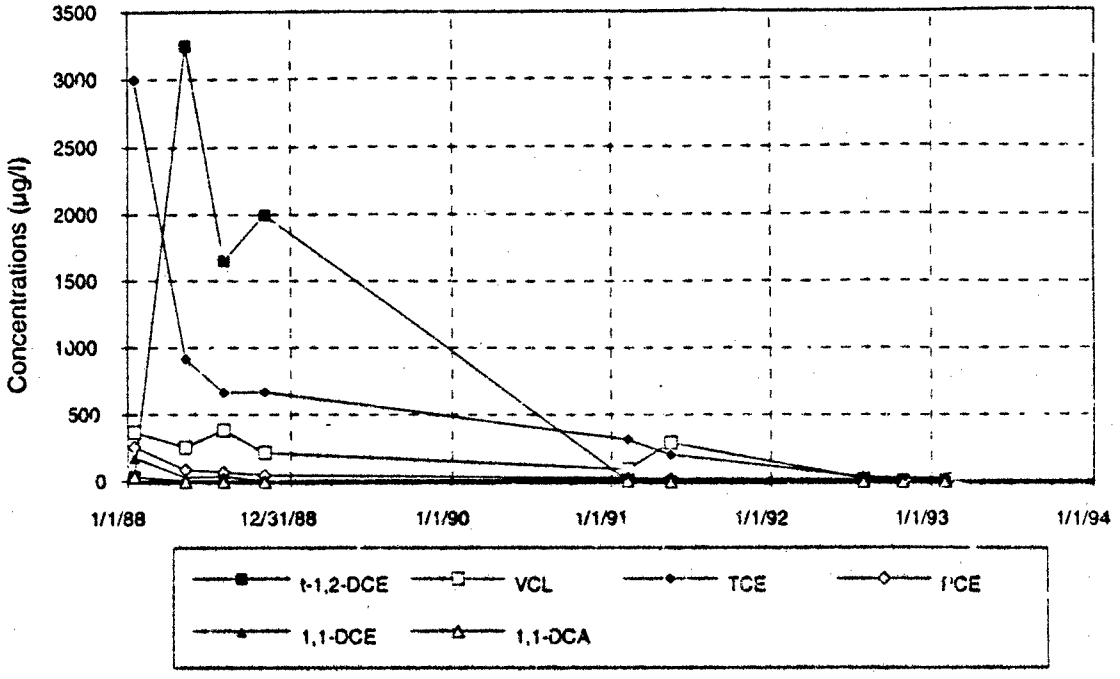
Biotransformation Processes

Microbial biological processes can transform chlorinated aliphatic compounds into other compounds. This can result in either complete mineralization of the compound to carbon dioxide and water, uptake and incorporation into the microorganisms as cell material, production of metabolic end products (cell wastes), or reduction to other chlorinated compounds. The term "biotransformation" refers to the biological processes that lead to any of these fates. In general, there are two major categories of biotransformation processes for chlorinated aliphatic compounds such as those found in the groundwater at the Davis Site. These are anaerobic dehalogenation and aerobic oxidation.

Anaerobic Dehalogenation

Anaerobic dehalogenation is the process of removing halogens from halogenated compounds by replacing them with hydrogens under anaerobic conditions. Since this reaction is a reduction, an electron donor is necessary. Electron donors can be a reduced organic compound or decaying cell material (Rittman et al., 1988). Electrons are transferred from the donor to an electron-transfer mediator, which then transfers the electrons to the halogenated acceptor.

When the electron and an accompanying hydrogen ion are accepted by the halogenated molecule, a halogen ion is released (such as a chloride ion). For example, removal of a chloride ion from PCE will result in TCE, removal of a chloride ion from TCE will result in DCE, removal of a chloride ion from DCE will result in VCL, and removal of the final chloride ion will result in ethene, which can be further reduced to ethane. These products of dehalogenation are known as daughter products. The daughter products generated by reductive dehalogenation of PCE have been identified as TCE, DCE, VCL, DCA, chloroethane, and both ethene and ethane (Beeman et al., 1993). Therefore, anaerobic dehalogenation has been shown capable of biotransforming all of the principle groundwater contaminants present in the groundwater at the Davis Site.



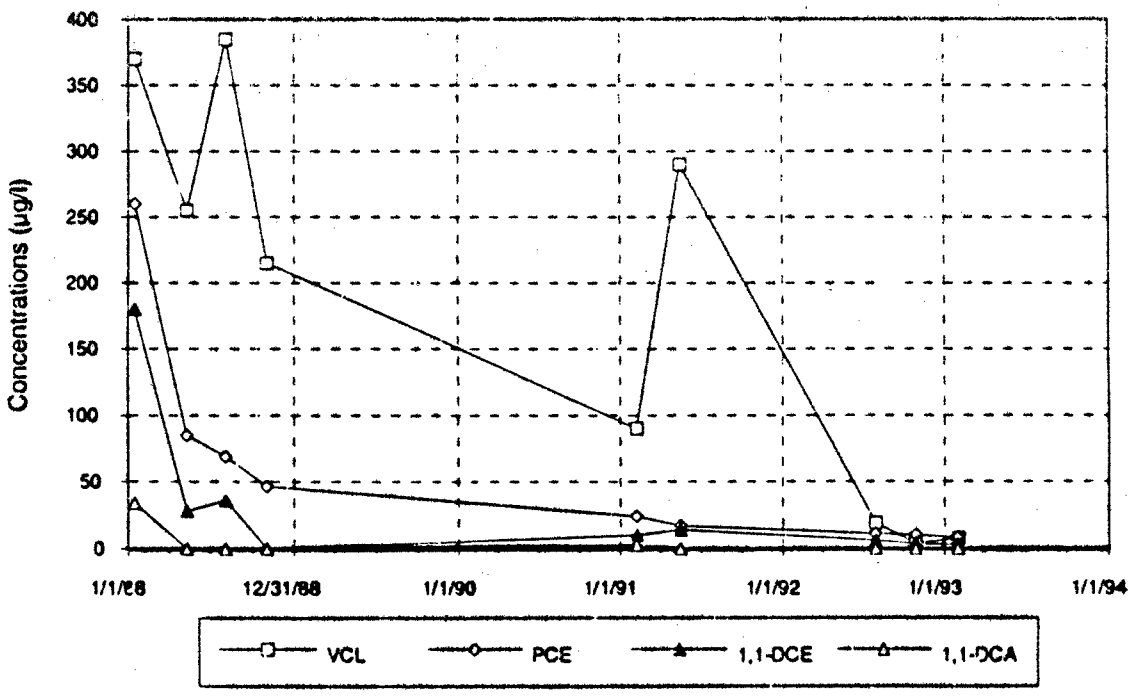


FIGURE N-2
HISTORICAL CONTAMINANT CONCENTRATIONS MW-1
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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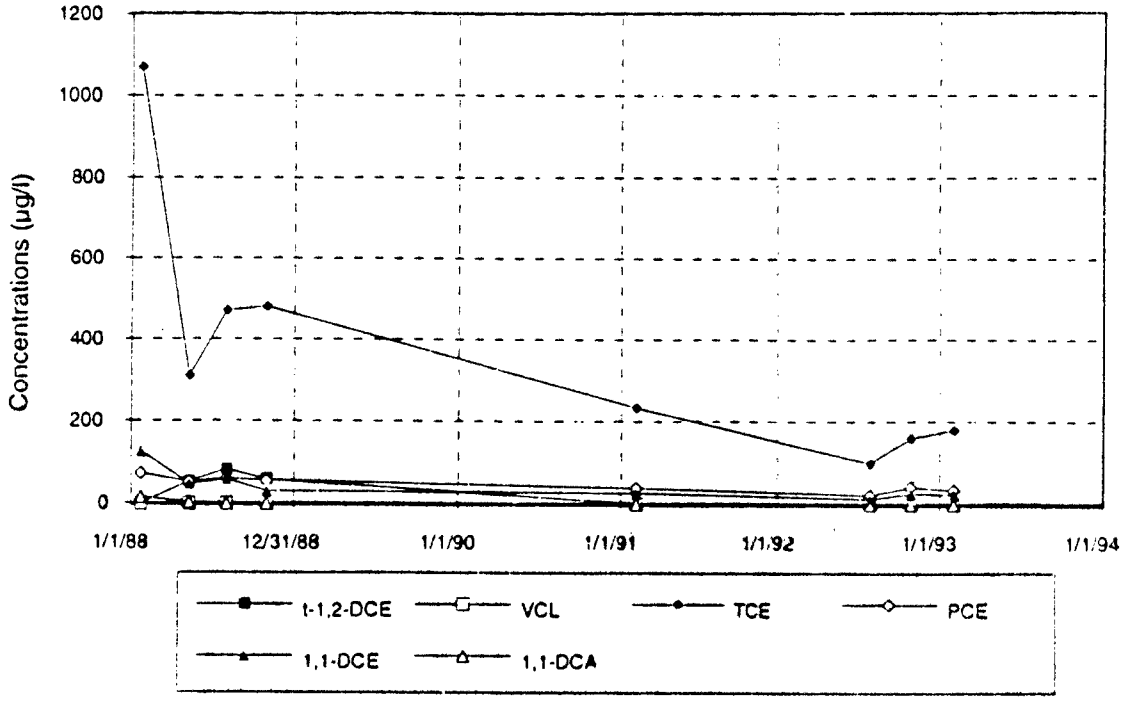

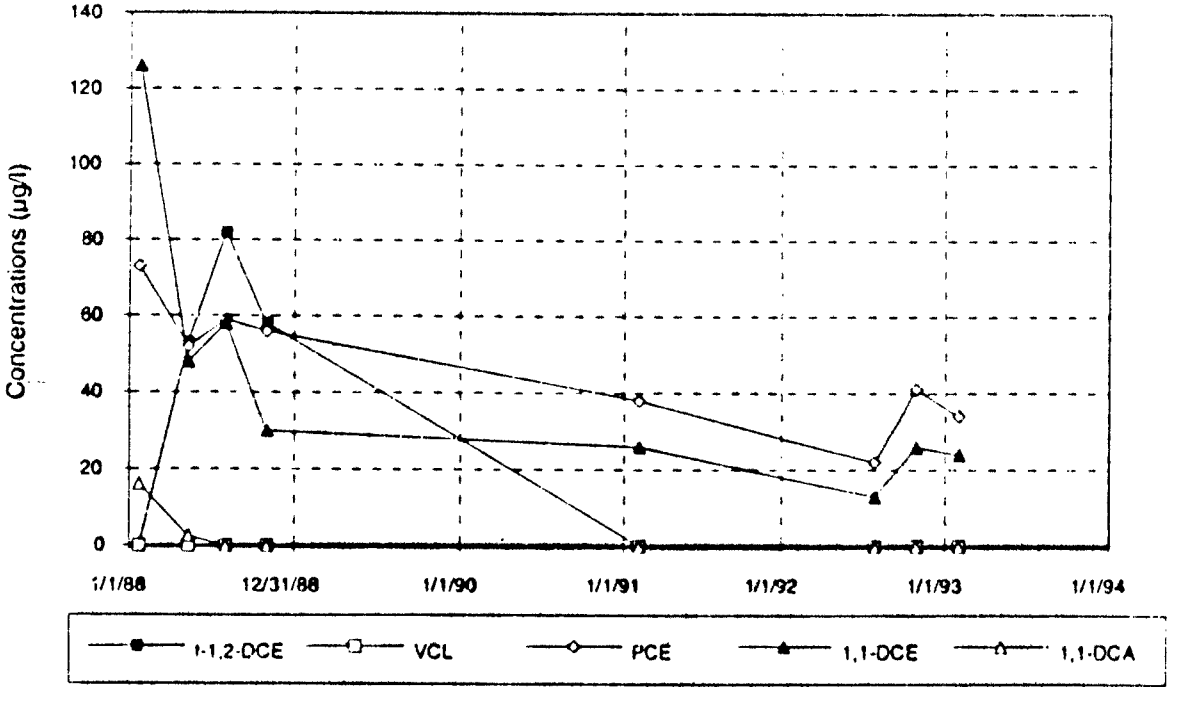

FIGURE N-3
HISTORICAL CONTAMINANT CONCENTRATIONS MW-2
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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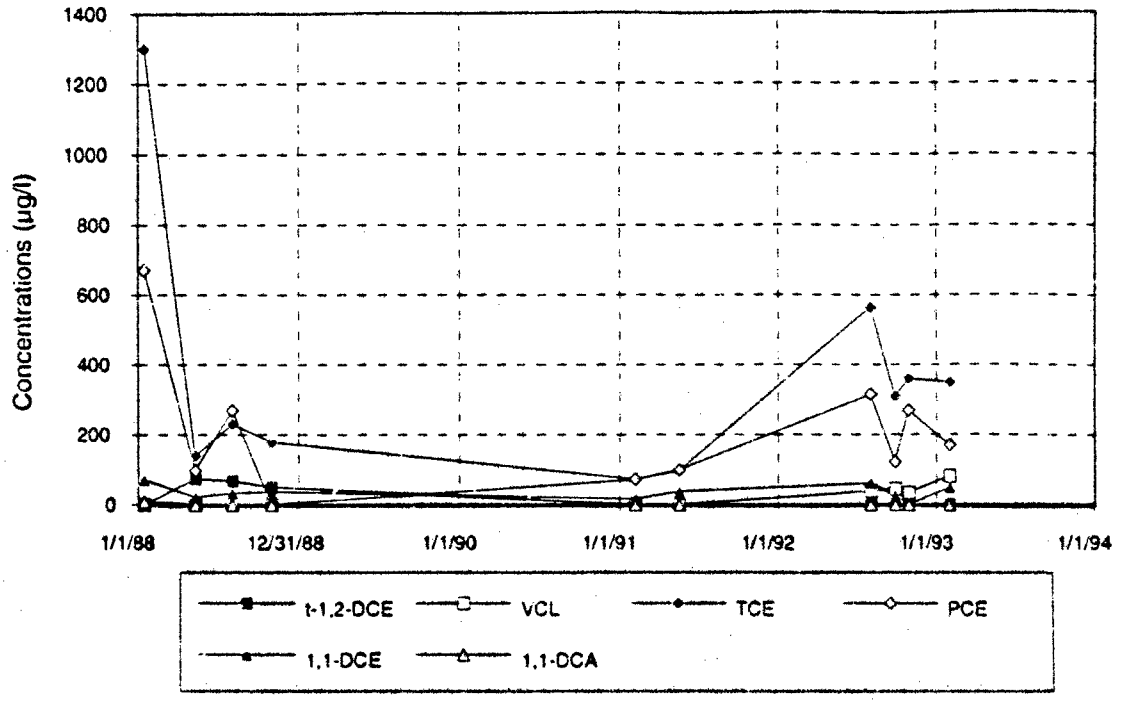

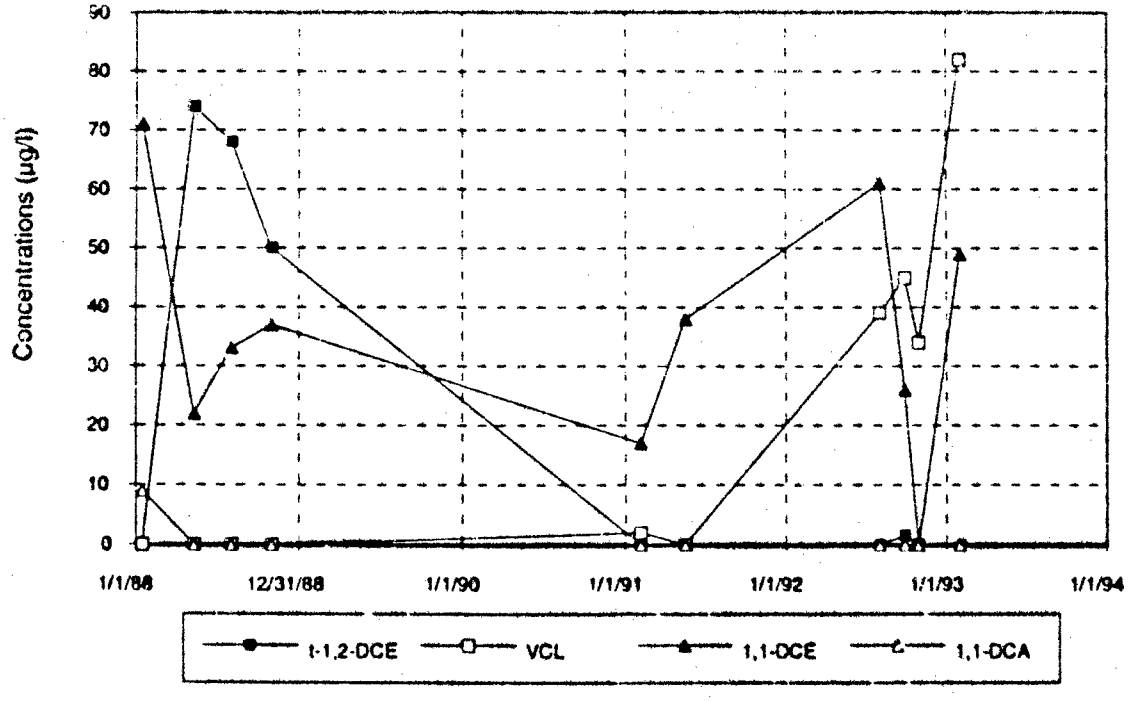

FIGURE N-4
HISTORICAL CONTAMINANT CONCENTRATIONS MW-3
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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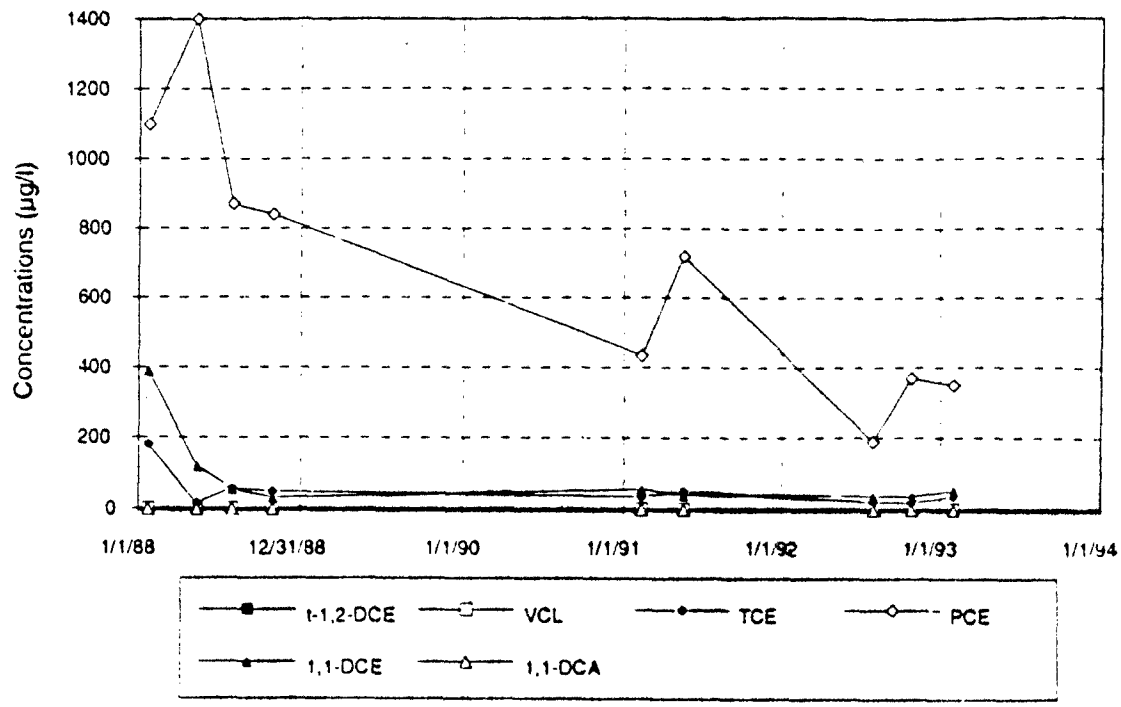

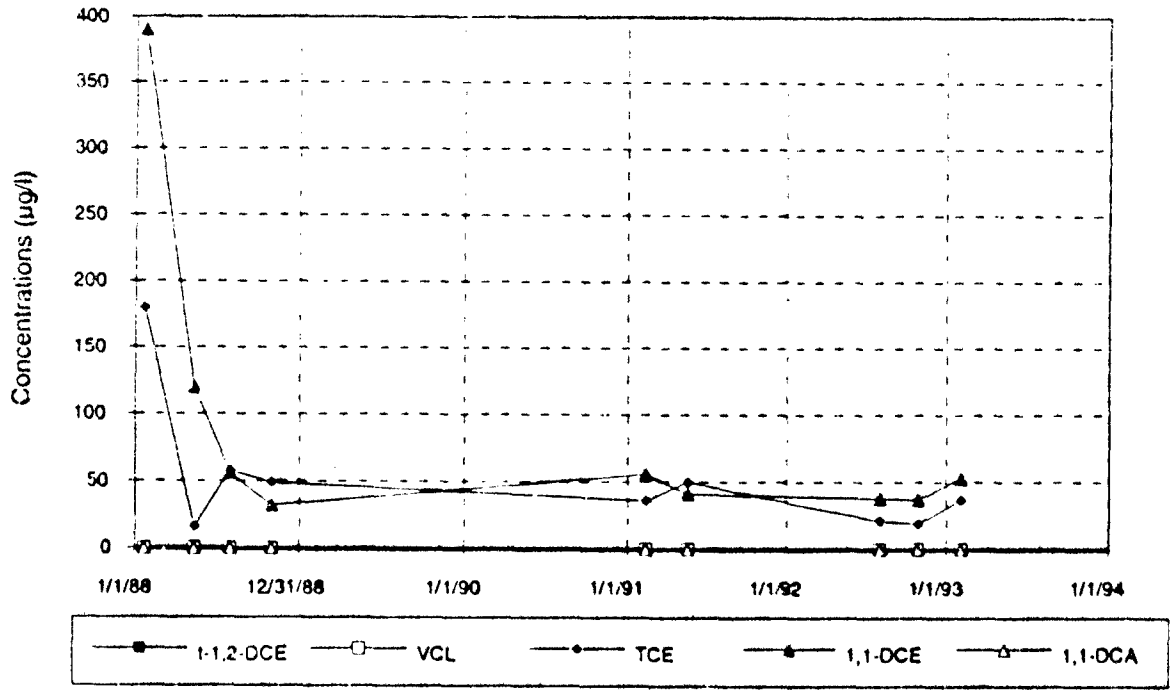

FIGURE N-5
HISTORICAL CONTAMINANT CONCENTRATIONS MW-5
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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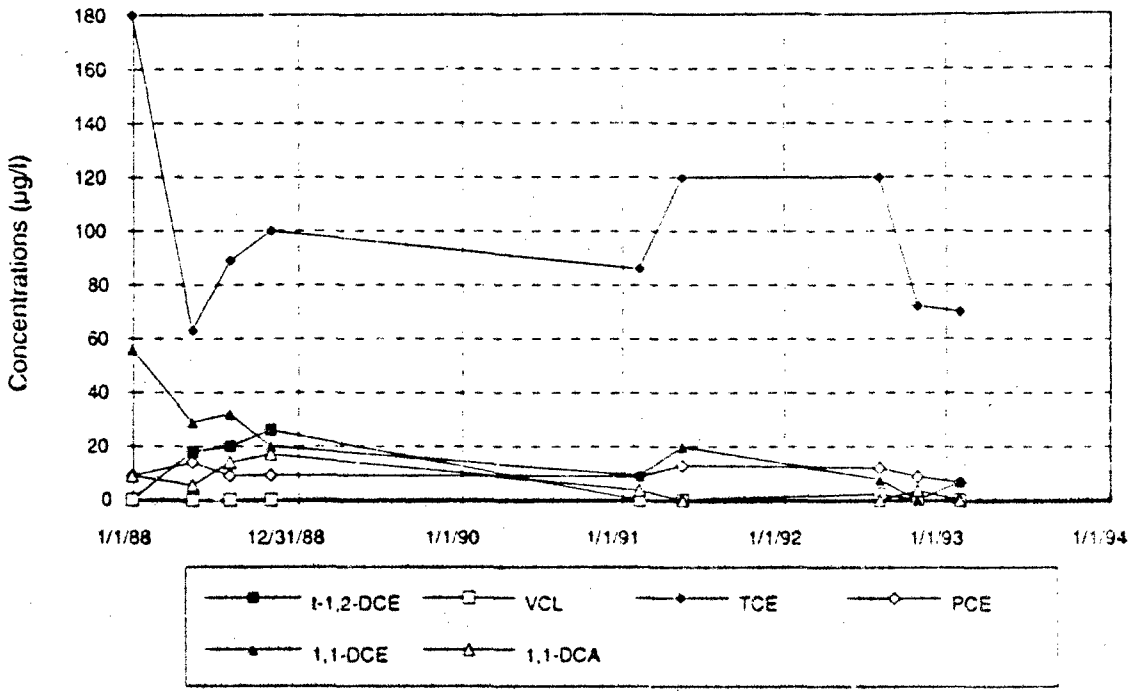

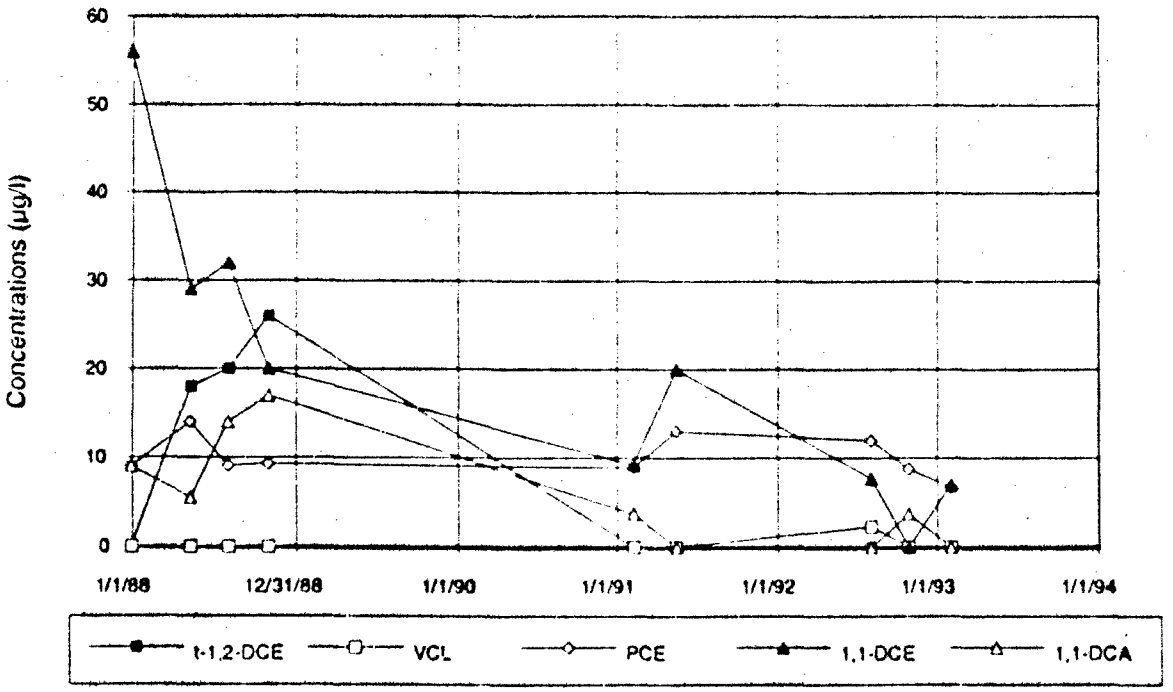

FIGURE N-6
HISTORICAL CONTAMINANT CONCENTRATIONS MW-7
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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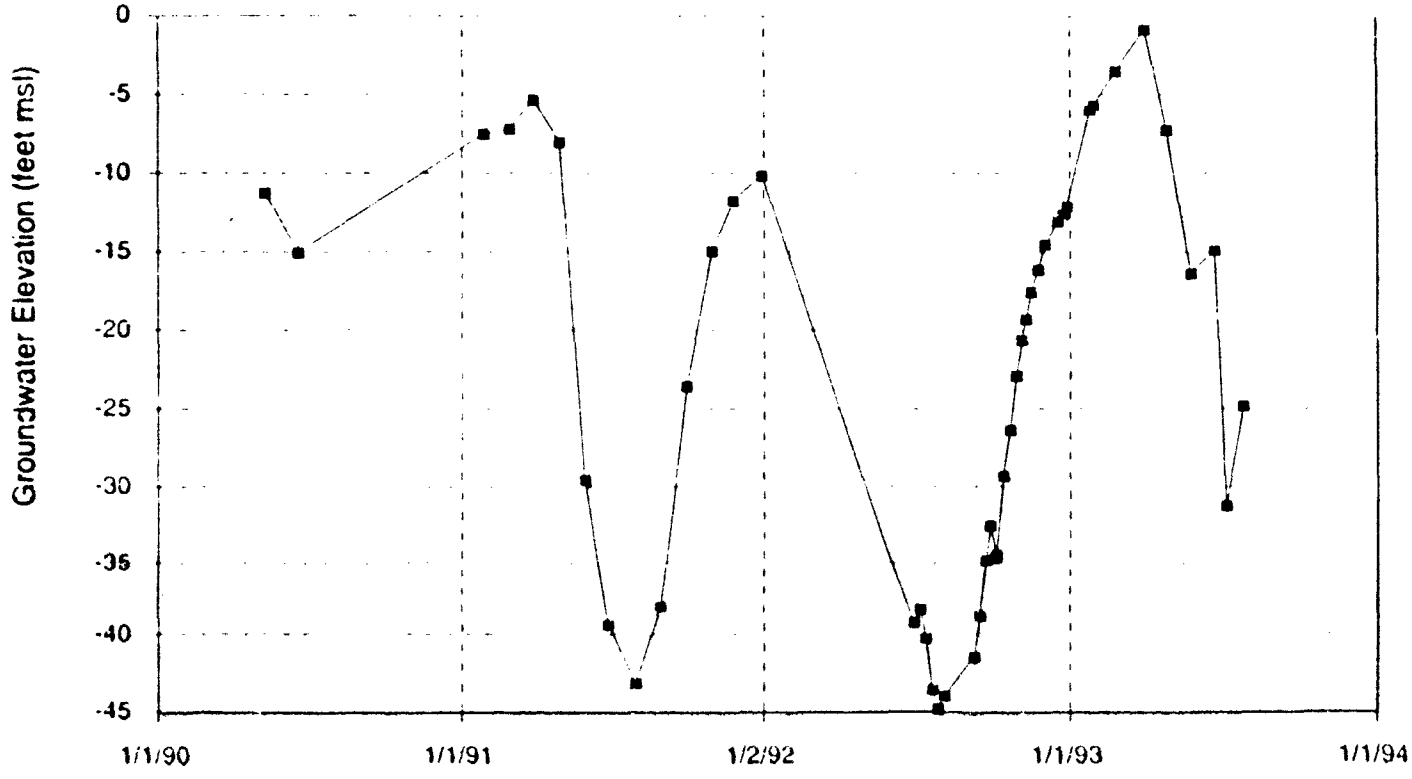

Note: Elevation of ground surface at MW-5 is 25 feet above mean sea level.

FIGURE N-7
GROUNDWATER ELEVATIONS MW-5
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Aerobic Oxidation

Aerobic oxidation of chlorinated aliphatic compounds requires a primary carbon source (electron donor), an electron acceptor (molecular oxygen), and certain monoxygenase or dioxygenase enzymes. Production of these nonspecific enzymes is induced by the presence of certain organic compounds referred to as primary substrates, but they fortuitously oxidize the chlorinated aliphatics such as TCE. This process is known as cometabolism. Primary substrates known to induce production of oxygenase enzymes are toluene, ethyl benzene, phenol, methane, propane, and ammonia (Folsom, 1992). Cometabolism has been shown capable of biotransforming all of the main contaminants present in the groundwater at the Davis Site except for PCE. Unlike anaerobic dehalogenation, the cometabolism of a chlorinated aliphatic compound does not result in specific reduced daughter products such as other chlorinated aliphatics. Daughter products are produced, but they are generally thought to be nonhazardous and are typically not measured.

Required Conditions for Biotransformation

Knowing the conditions required for biotransformation of chlorinated organic compounds assists in determining if the process is occurring at a site. For example, a decrease in TCE concentration over time measured at a monitoring well may not be caused by biotransformation, but to movement of the TCE away from the well location by groundwater flow. Conversely, biotransformation could be occurring in the vicinity of a monitoring well that does not show change in contaminant levels over time, because of continual addition of new contaminant mass at the same rate as it is being transformed.

Since cometabolism requires a primary substrate enzyme induction, absence of the inducer indicates low likelihood of cometabolism occurring. Even if an inducer is present, the specific microorganisms capable of cometabolism must also be present for the process to occur. Molecular oxygen must also be present as an electron acceptor. The essential elements of inducer, capable organisms, and molecular oxygen must be present at a site for cometabolism of chlorinated aliphatic compounds to occur.

The essential elements required for anaerobic transformation of chlorinated aliphatic compounds are capable organisms, an electron donor, an electron acceptor, and reducing conditions (absence of molecular oxygen).

Approach

The site data were evaluated for indications of either cometabolism or anaerobic dehalogenation of the site contaminants. The data were analyzed for presence of cometabolism inducer compounds, presence of a primary carbon source, and for significant changes in concentrations of anaerobic transformation daughter products.

Also, Figures N-2 through N-6 were used to evaluate changes in concentrations of site contaminants over time that may be caused by biotransformation.

Interpretation

Cometabolism

Little data exist to assess whether the essential cometabolic elements of inducer compound, cometabolic capable organisms, and molecular oxygen are present in the groundwater. However, because of the cyclical rising and falling pattern of the groundwater, it is possible that this action acts like a pump to draw air through the vadose zone to the upper portion of the groundwater.

The only inducer compound detected in the groundwater is toluene. The highest concentration detected is 23 µg/l in MWD-10. However, it does not appear to be widespread in the groundwater. Phenol and ethyl benzene have been analyzed for but have never been detected. The groundwater has not been analyzed for methane, propane, or ammonia. Although it is apparent that concentrations of the chlorinated organic compounds have decreased with time at many of the monitoring wells (Figures N-2 through N-6), it is uncertain if these reductions are due to cometabolism or other mechanisms. However, it is unlikely that cometabolism plays a significant role.

It is unlikely that cometabolism accounts for a significant portion of the decreases shown by the concentration versus time plots for two reasons. The first is that a relatively large amount of inducer compound compared to chlorinated organic compound is required for cometabolism, and there is no evidence that this much inducer is present. Studies using indigenous methanotrophic bacteria have shown that 100 to 300 grams of methane is required to cometabolize 1 gram of TCE, and that cometabolism of 0.2 to 1 gram of TCE requires 2 grams of phenol using the bacterium *Pseudomonas cepacia* strain G4, or 4 to 8 grams of toluene using *Pseudomonas mendocina* (Ensley, 1992). The second reason is that PCE decreases at approximately the same rate as TCE in many of the plots. Since cometabolism has not been shown capable of biotransformation of PCE, it is unlikely that these decreases are caused by cometabolism.

Anaerobic Dehalogenation

Little data exist to assess if the essential elements to support anaerobic dehalogenation are present. Though no direct microbial evidence is available, it is likely that capable organisms are present, since organisms capable of anaerobic dehalogenation are fairly common. No ethene or ethane data are available to discern the presence of these potential daughter products.

Although diesel is not a widespread contaminant, it has been detected in MW-1, MW-3, and MW-7 at low levels (85 µg/l, 67 µg/l, and 93 µg/l, respectively). Diesel constituents could provide electron donors.

Evaluation of the contaminant concentration versus time curves resulted in some interesting observations regarding potential daughter products. MW-5 is thought to be located near the area that solvents may have been used to control weeds. Figure N-5 shows that since 1988, PCE, 1,1-DCE, and TCE have been the major groundwater contaminants and that each has decreased with time. It is unlikely that this decrease is caused by anaerobic dehalogenation since neither VCL nor t-1,2-DCE has been detected.

VCL and t-1,2-DCE have been detected in wells downgradient (south) of MW-5. These compounds are detected fairly consistently in MW-1, MW-3, and MW-7. In MW-2, t-1,2-DCE has been detected, but VCL has not been detected.

Figure N-2 depicts the MW-1 data and shows relatively large concentrations of t-1,2-DCE and VCL with the highest concentrations occurring in 1988 followed by a downward trend. Figure N-4 shows the MW-3 data. These data are especially interesting. In 1988, t-1,2-DCE is at its highest concentration, and it decreases to a nondetectable level by 1991, when VCL begins to increase in concentration. Figure N-6 presents data for MW-7 and shows TCE and PCE concentrations remaining relatively constant since 1988, and then a slight amount of VCL being detected in 1992.

These findings are interesting because of the apparent lack of primary substrate in the groundwater in the vicinity of these wells. Analysis of the groundwater in these wells for total organic carbon (TOC) or chemical oxygen demand (COD) would help to determine if sufficient electron donor compounds are present to account for these observations.

In the vicinity of soil gas Monitoring Well CH-5, which is located between MW-1 and MW-3 and upgradient from MW-2 and MW-7, underground diesel storage tanks leaked and contaminated the vadose zone soils with diesel. The approximate area of vadose zone diesel contamination is indicated in Figure N-1. In 1988, the soil adjacent to the tanks was excavated. However, the excavation did not remove all of the contaminated soil. Diesel has been measured to a depth of 70 feet.

Analysis of soil gas samples taken from soil gas monitoring well CH-5 has shown 0 percent oxygen, 10 percent carbon dioxide, and 2 percent methane. These results indicate anaerobic conditions. In addition, CH-5 is the only soil gas well where VCL has been detected. It was detected at 510 parts per billion by volume (ppbv). It is possible that the VCL is a daughter product of anaerobic dehalogenation of PCE, TCE, or DCE.

The groundwater in this area falls from 40 feet to 70 feet below ground surface from February to June because of regional pumping, and then climbs back up because of

recharge. It is possible that as the water moves up, VCL in the vadose zone is encountered, causing a portion of it to dissolve and to be transported laterally by horizontal groundwater movement. Diesel constituents could also be dissolved by the rising groundwater, which could provide electron donors to support anaerobic dehalogenation in the groundwater. The VCL detected in groundwater Monitoring Wells MW-1, MW-3, and MW-7, may be a result of these two mechanisms.

Conclusions and Recommendations

Conclusions

The following conclusions are made regarding natural biological attenuation of chlorinated organic compound in groundwater at the Davis Site.

- Insufficient data are available to make a thorough evaluation of the extent of biotransformation at the site.
- It is unlikely that cometabolism accounts for a significant portion of the decreases shown by the concentration versus time plots.
- Anaerobic dehalogenation may be occurring in the vicinity of soil gas Monitoring Well CH-5. This process may be a source of VCL to the groundwater.

Recommendations

To further evaluate the site for biotransformation of chlorinated organic compounds, it is recommended that the groundwater and soil gas sampling schemes be modified to look for indications of cometabolism or anaerobic dehalogenation processes. Measurement of dissolved oxygen would help to discern the oxidative state of the groundwater. Analyses of the site groundwater for inducer compounds would provide valuable information to more thoroughly assess if cometabolism is occurring, and analyses of the site groundwater for COD or TOC would help to identify areas that may have sufficient electron donor compounds to support anaerobic dehalogenation. Analysis of the groundwater from Monitoring Wells MW-1, MW-3, and MW-7 and the soil gas from soil gas Monitoring Well CH-5, for ethene and ethane, may help determine if VCL is being dehalogenated.

The bioventing demonstration project that is planned for the area near soil gas Monitoring Well CH-5 should be evaluated for its impact on the anaerobic dehalogenation process apparently occurring at that location. Introduction of oxygen to the subsurface will inhibit the anaerobic dehalogenation process and therefore would inhibit VCL production. Methanotrophic bacteria that may be present could potentially use the methane generated during the previous anaerobic conditions for cometabolism of the TCE, DCE, and VCL. However, if VCL is currently being dehalogenated to

ethene or ethane, then introduction of oxygen may be detrimental since PCE dehalogenation would cease.

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PREPARED FOR: Davis RI/FS Report

PREPARED BY: Jim Hartley/CH2M HILL, Sacramento
Alex Rafalovich/CH2M HILL, Redding

DATE: September 9, 1993

SUBJECT: Dual-Phase Extraction
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.13

Purpose and Scope

Dual-phase extraction has been proposed as a method of removing volatile contaminants that may be present in fine-grained soil within a zone of seasonal water table fluctuation at the Davis Global Communications Site (Davis Site). This zone of fine-grained soil occurs from a depth of approximately 40 feet to approximately 70 feet below ground surface (bgs) and consists predominately of silty lean to fat clays. As described in Chapter 3 of the Remedial Investigation/Feasibility Study (RI/FS) report, the fluctuation occurs as a result of regional pumping in the summer, countered by seasonal recharge in the winter. In this appendix, this zone is referred to as the intermittent capillary zone.

This technical memorandum is designed to provide the reader with increased understanding about how a dual-phase extraction system might be designed to remove soil vapor and groundwater contaminants from this intermittent capillary zone. This technical memorandum also identifies additional fieldwork needed before a dual-phase system can be designed for the Davis Site. Recommendations are made regarding: (1) *soil gas sampling* that needs to be done to better define the extent of contamination in the intermittent capillary zone and (2) procedures for a small scale *pilot test study* designed to estimate the air flow rates achievable from a dual-phase system.

Objectives of Dual-Phase Extraction

The primary objective of the dual-phase extraction system is to remove volatile organic compounds (VOCs) from the intermittent capillary zone to a point at which they are no longer a significant source of groundwater contamination. To accomplish this objective, the dual-phase system needs to achieve the following:

- Removal of mineral- and organic-phase sorbed contaminants that represent a long-term source of contaminants to the underlying groundwater
- Removal of vapor-phase contaminants that are actively migrating toward groundwater, in response to diffusional and advective gradients
- Removal of contaminants present in solution in the pore water, to intercept the contaminants that might be drawn toward the groundwater in this phase
- Removal of nonaqueous pure-phase contaminants that reside in the soil matrix

Subsurface Conditions

The soil in the intermittent capillary zone is described as a massive silty and sandy clay, moist, with some mineral accretions. No data on measured physical properties or contaminant presence and concentration have been collected to date, but evaluation of contaminant data above and below the zone of seasonal water table fluctuation suggest that VOCs have been and may still be present (refer to Chapter 4 of the RI/FS report).

Dual-Phase Extraction System Description

Dual-phase extraction consists of the simultaneous removal of soil gas and water from a single well screened at or above the water table. Dual-phase pumping can be accomplished using a downhole submersible pump and an aboveground vacuum source, or a single aboveground high vacuum source configured to remove both water and soil gas. The system described in this technical memorandum consists of a downhole submersible pump to remove contaminated groundwater and an aboveground high vacuum liquid ring blower designed to remove contamination from the vadose zone. An illustration of the major components of this system is presented in Figure O-1.

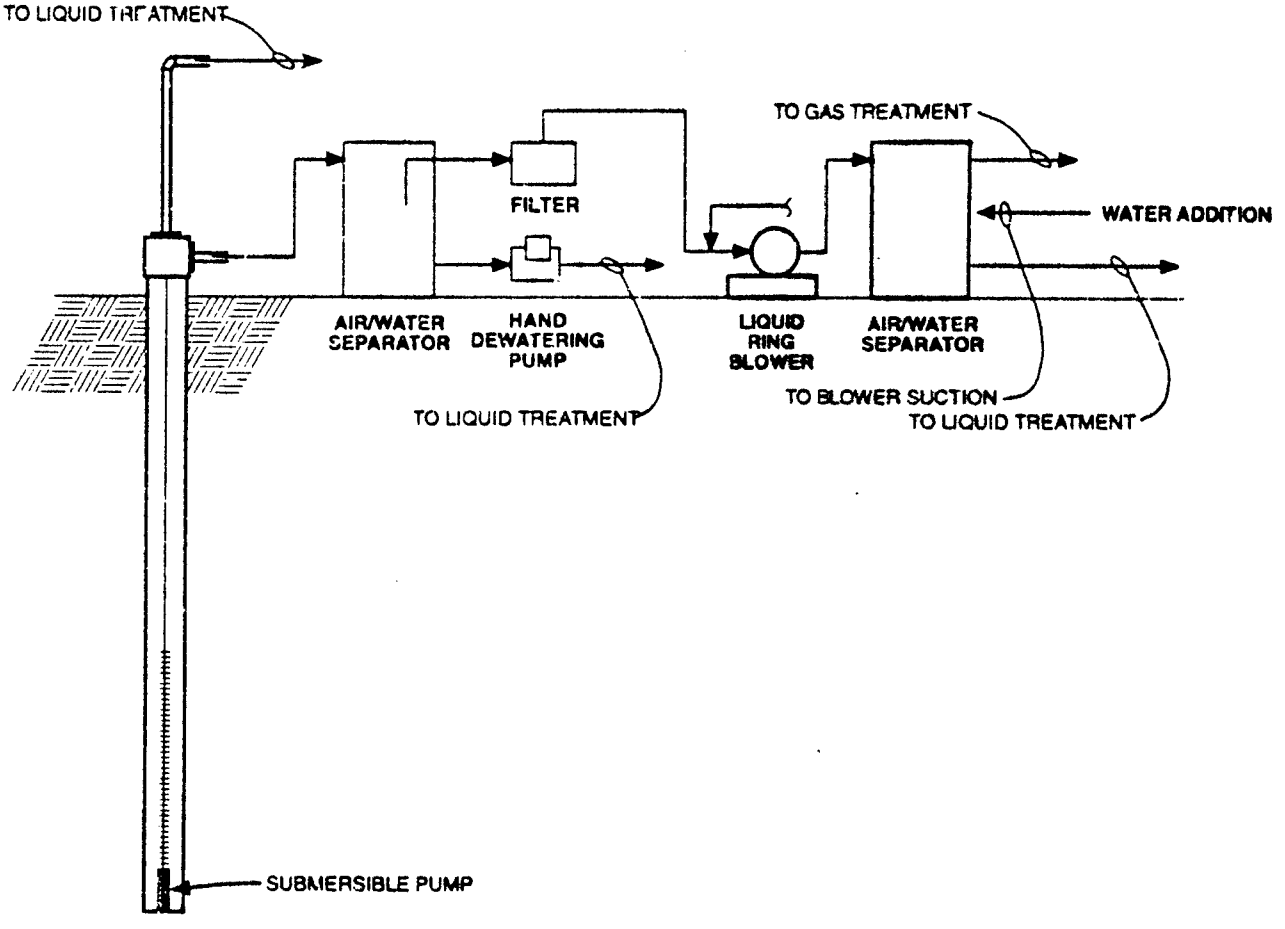

FIGURE O-1
HIGH VACUUM DUAL-PHASE SYSTEM SCHEMATIC
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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The dual-phase system option shown in Figure O-1 was selected as the best one for the Davis Site because of the generally fine-grained nature of the intermittent capillary zone. Normally, these types of soils retain a high moisture content after wetting (or submergence) and are likely to have low air permeabilities. The high vacuum liquid ring blower can have the effect, over time, of evaporating excess moisture from the soil above the water table in the vicinity of the extraction well. The reduction in moisture content leads to shrinkage in plastic soils, which may lead to the formation of fractures, producing an increased air permeability and greater air flows. This, in turn, can accelerate the removal of volatile contaminants and increase the zone over which removal effectively occurs, as shown in Figure O-2.

The submersible pump of the proposed system would be used to depress the water table in the vicinity of the extraction well to increase the zone that could be affected by the high vacuum. Depending on groundwater conditions, the submersible pump could potentially only need to be operated during wintertime, high water table conditions, and may not need to be used during the summer (refer to Figure O-3).

Discussion and Recommendations

The applicability of a dual-phase approach is based on site characteristics that make conventional soil vapor extraction and groundwater pumping difficult techniques to achieve adequate contaminant removal. The fine-grained nature of the soil in this zone is expected to have very low hydraulic conductivities, which could lead to unacceptably low pumping rates during the 6 months or so that this zone is saturated and could be pumped. The seasonal wetting of the soil is likely to maintain soil conditions such that the air permeability will be limited by high levels of soil saturation. For both water and air pumping systems, the soil may have unfavorable air and water flow characteristics unless measures are implemented to improve the soil permeability.

For a dual-phase system to be designed to achieve its cleanup objectives, specific data will be needed on the contamination extent in the zone to be treated and certain physical properties of the soil. Each well is likely to be effective in a relatively limited zone, possibly on the order of one to two times the depth of embedment of the well in the fine-grained unit. For this reason, some information on areas of contaminant concentration would permit the more effective placement of dual-phase wells. In terms of physical properties of the soil, the feasibility of the dual-phase approach hinges on the ability of the soil to sustain air flow, which may require that the soil be modified through the application of a high vacuum or other means. The degree to which an adequate effective air permeability can be established will influence the feasibility of this approach to remove volatile contaminants.

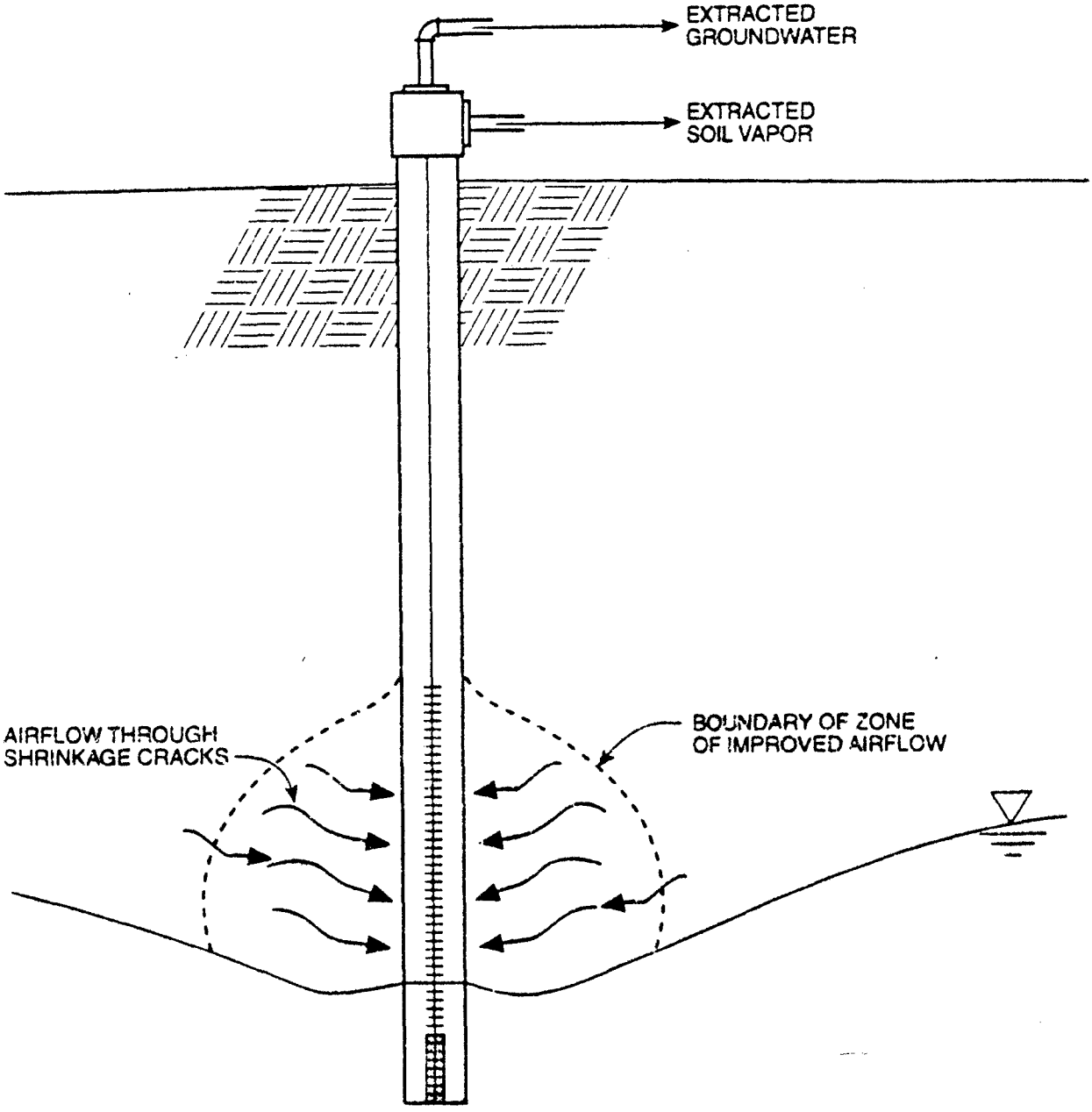

FIGURE O-2
ZONE OF IMPROVED AIRFLOW FORMED DURING DUAL-PHASE EXTRACTION
DMS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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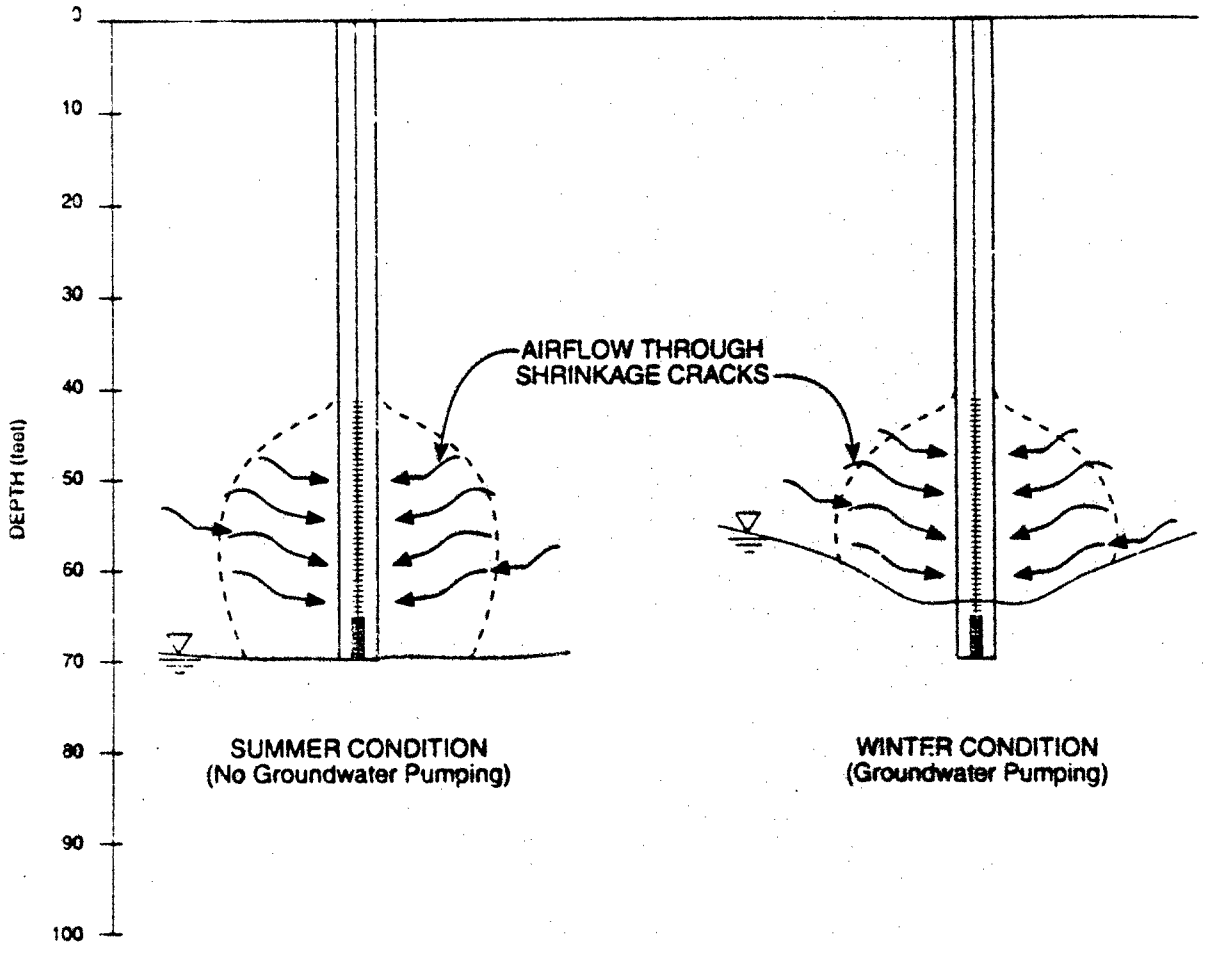

FIGURE 0-3
IMPACT OF WATER TABLE FLUCTUATIONS ON DUAL-PHASE SYSTEM OPERATIONS
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Additional Soil Gas Sampling Recommendations

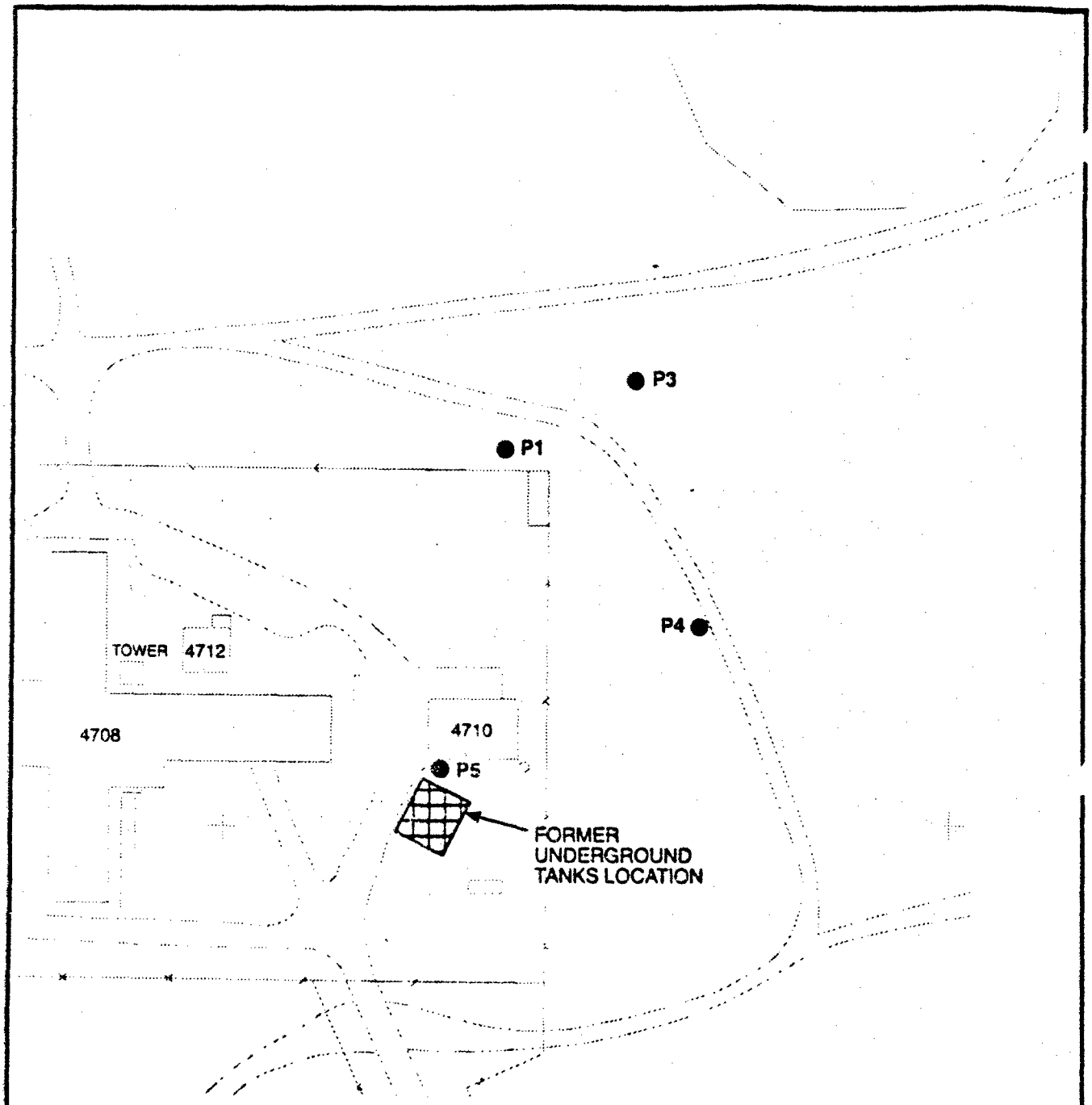
Recommended soil gas sampling locations necessary to support the design of a dual-phase system are presented in Figure O-4. Three samples are recommended to be taken from the northeast quarter of the site because this is a suspected source area of VOCs. One sample (P5) is recommended near the location of former leaky underground tanks where significant diesel contamination is already known to exist. All of the samples would be taken from piezometers that have already been constructed. The screened intervals that should be used when taking the samples are summarized in Figure O-4. The construction details of the piezometers are presented in Appendix S, Well Construction Data, of this report. The results of soil gas analyses should be used to estimate the mass of contaminants in the intermittent capillary zone and to evaluate the value of a focused dual-phase system contaminant removal program in the zone.

Recommended Dual-Phase System Pilot Tests

The key physical performance characteristic of the soil to evaluate its suitability for dual-phase extraction is the tendency of the soil to shrink in volume upon removal of moisture. This characteristic would indicate the likelihood that sufficient air flow could be produced in soils that are currently saturated, following the "development" of these wells with a high vacuum. Figure O-5 conceptually illustrates the flow improvement over time that might be expected because of the application of a high vacuum system.

Existing Extraction Well EW-1B could be used to evaluate this characteristic. This well is ideally suited for dual-phase testing because of its long 60-foot screened interval, which covers the zone of seasonal water table fluctuation. Testing is recommended at the well to estimate the magnitude of flow improvement that can be achieved by applying a high vacuum. A vacuum pump capable of pulling 20 scfm at 25 inches of mercury should be used during the testing. The initial flow rate (Q_o) should be measured as well as developed flow rates (Q_d) at periodic time intervals. An automated continuous data logger could be used to record the flow data. The ratio of Q_d/Q_o should be plotted as a function of time. The test should be terminated when the ratio Q_d/Q_o becomes constant. The final Q_d/Q_o ratio provides a measure of the amount of flow improvement achievable in the soil for a given applied vacuum.

Offgas emissions generated during the pilot testing also need to be sampled. In all likelihood the airstream will be contaminated and depending on the levels detected in the sampling a small offgas treatment unit (i.e., carbon canisters) may need to be added to the pilot test. It is anticipated that the pilot test will not take longer than 10 days to complete, based on previous experience.



Piezometer	Sampling Interval (ft bgs)
P1	46 to 56
P3	46 to 56
P4	46 to 56
P5	45 to 55

SCALE (Approximate)

0 100 FEET

LEGEND

● PIEZOMETER SAMPLING POINT

FIGURE 0-4
SOIL GAS SAMPLING LOCATIONS NEEDED TO SUPPORT A DUAL-PHASE EXTRACTION SYSTEM DESIGN
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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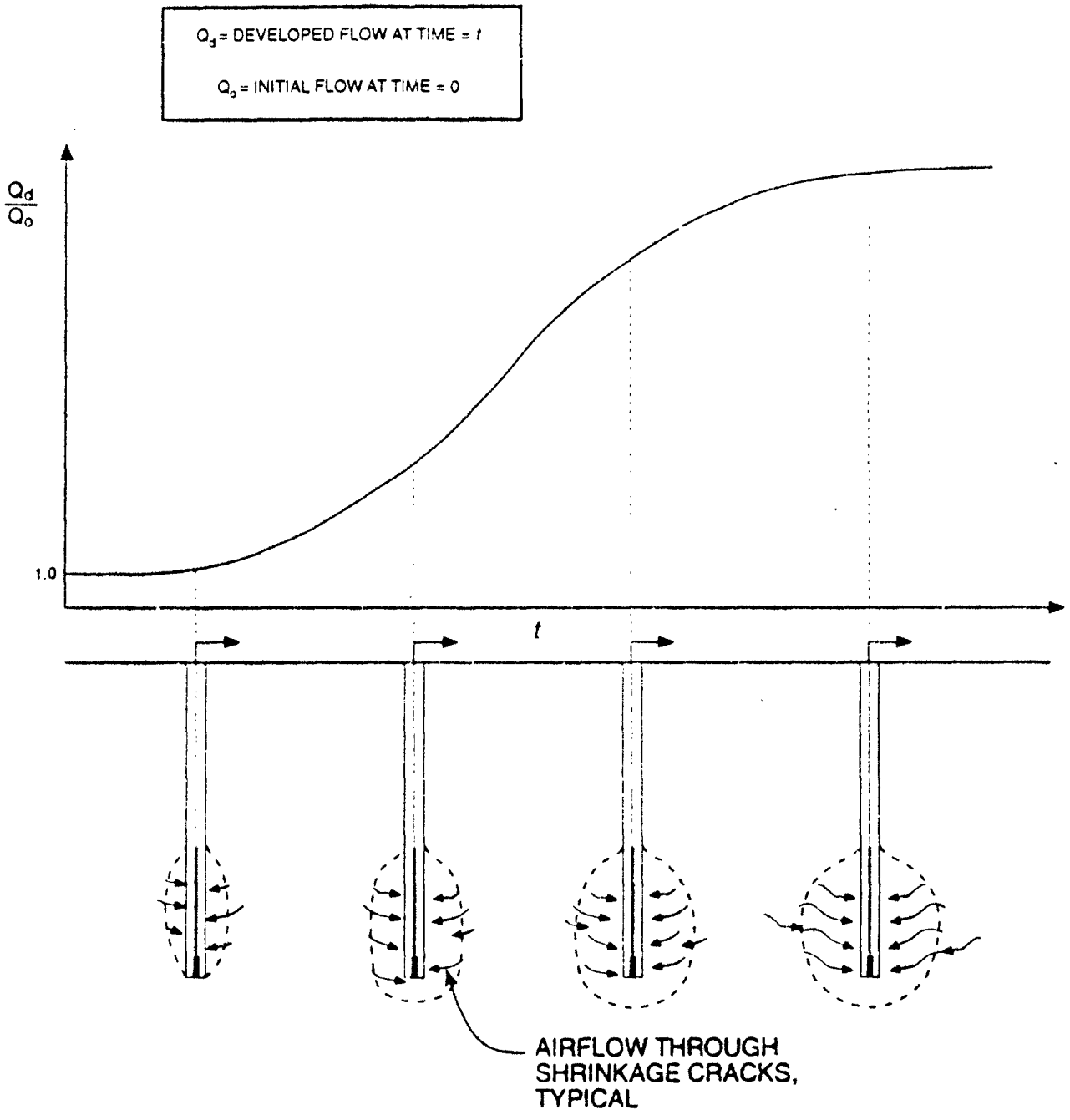

FIGURE 0-5
FLOW IMPROVEMENT OVER TIME USING DUAL-PHASE EXTRACTION
DAVIS GLOBAL COMMUNICATIONS SITE
McCLELLAN AIR FORCE BASE
YOLO COUNTY, CALIFORNIA

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Summary

In summary, a dual-phase extraction system may be the best solution for removing VOC contaminants from the zone of seasonal water table fluctuation at the Davis Site (40 to 70 feet bgs). By virtue of its ability to dewater this zone, and also improve the soil airflow characteristics, dual-phase extraction potentially offers some real advantages over standard soil vapor extraction or groundwater extraction.

Additional data are required on the nature of contamination and physical soil properties within the zone of seasonal water table fluctuation before final conclusions can be made regarding the potential usefulness of a dual-phase extraction system. Specifically, soil gas sampling to be conducted to estimate the extent of contamination, and pilot testing needs to be conducted to estimate the amount of flow improvement that is obtainable from the soil in the intermittent capillary zone. Once these data are obtained, the necessity of a dual-phase system can be evaluated, and a final dual-phase system design can be developed, if needed.

PREPARED FOR: Davis RI/FS Report

PREPARED BY: Artemis Antipas/CH2M HILL, Seattle

DATE: September 9, 1993

SUBJECT: Data Validation
Davis Global Communications Site
Delivery Order No. 5055

PROJECT: SAC28722.55.18

Purpose and Scope

This technical memorandum summarizes the analytical methods, describes the data validation methodology and the contents of data validation reports, and provides an overall assessment of the data. The entire data validation package is available upon request from CH2M HILL.

Approach

Analytical Methodology

The analytical parameters and methods used are listed in Table P-1.

Table P-1
Analytical Parameters and Methods

Parameter	Method
Toxicity Characteristics Leaching Procedure (TCLP)	
TCLP volatiles	CLP
Purgeable halocarbon/bromatics	8010/8020
Semivolatiles	CLP
Metals	CLP
Total petroleum hydrocarbons	418.1
Total fuel hydrocarbons (diesel)	Ca Luft (modified 8015)
Percent moisture	ASTM D2216
Bulk density	ASA No. 9 30-2
Air volatiles	TO-14
Atmospheric gases	ASTM D 5416

Volatiles, semivolatiles, and metals were analyzed using the Environmental Protection Agency (EPA) Contract Laboratory Program (CLP) protocols (EPA 1990 CLP Statement of Work). For the parameters that are not covered under the EPA CLP protocols the standard methods referenced in Table P-1 were used. The quality assurance/quality control (QA/QC) methodology implemented for the non-CLP parameters was based on the quality assurance project plan.

The laboratories that carried out the analyses in addition to having CLP capability are state certified. The data have been reviewed outside the laboratories to ensure that the above-noted specifications were implemented for each sample and parameter. The data validation process is described in more detail in the following paragraphs.

Data Validation

Data have been reviewed at the laboratory as well as outside the laboratory by an independent chemist for conformance to the above-noted analytical protocols.

The data validation was carried out in accordance with EPA Functional Guidelines. Individual data validation reports have been prepared for each specific sample delivery group (SDG) and each specific parameter. The laboratory groups samples into SDGs; the samples in an SDG have common QC data as they are run consecutively. The individual reports were subsectioned according to the table of contents for the EPA Functional Guidelines. Each section detailed protocol deviations if any. The subsections summarized the outliers, if any, with the following minimum information:

- Affected sample numbers
- Affected parameters
- Quantitative listing of specific deviation
- EPA criteria for the noted deviation
- Applicable data flag per EPA guidelines
- Flag description as to whether it was caused by laboratory error (designated as "protocol" flag), matrix, or according to guidelines ("advisory" flag)

These SDG specific detailed reports are kept in project files. All the samples have been reviewed for QC data in accordance with EPA guidelines to include checks for proper methodology, level of QC effort (frequency of runs), and for conformance to EPA defined quantitative control limits. Ten percent of the samples have been checked for raw data (i.e., calculation algorithms, transcription errors, and special identification errors). Raw data checks result in corrections, if any, as opposed to flags. Raw data checks on 10 percent of the samples did not show any significant errors; thus, no further raw data checks were carried out as this is cost prohibitive and technically

not necessary because of QA planning and implementation prior to and during the analyses.

Data validation flags for the specific SDGs have been summarized in tables for project usage. The protocol flags have been entered into the database and provided in this text. The flags originating from the laboratory have not been presented in the table since the data validation flags incorporate data usage qualifications. The flags originating from the laboratory are kept in the main database and the laboratory hard copies. The only laboratory qualifiers included here are the designaters for below detection limit values.

Sample qualifications for contamination observed in laboratory blanks have been detailed in the individual report in accordance with EPA guidelines. These qualifications have been incorporated into the data table in this text. Qualifications for field blank contamination, if any, are carried out on a projectwide basis, since the field blanks do not necessarily correspond to only the samples in the specific SDG.

Data Assessment Interpretation

Validated data have met and exceeded project quality assurance goals as described in the quality assurance project plan. The data completeness is found to be over 95 percent. With the current state of practice in this area, this database is of high quality and provides detailed QC information to establish reproducibility and comparability; therefore, the data are appropriate for quantitative usage with attention to qualifiers in data validation reports described above.

Accuracy and precision values as defined in the quality assurance project plan have been summarized and included in project files along with data validation reports for data users. This package is available upon request from CH2M HILL.